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ALLEN has taught for more than thirty years as a faculty member at the Massachusetts Institute of Technology and Yale University, and as an invited guest at institutions in the U.S., South America, Europe, and Asia. He is a Fellow of the American Institute of Architects. He has designed more than fifty constructed buildings and is the bestselling author of *The Architect's Studio Companion*, *Structural Detailing*, *Fundamentals of Residential Construction*, and *Shaping Structures: Statics and Dynamics*, published by Wiley.

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ISBN 0-471-21903-7



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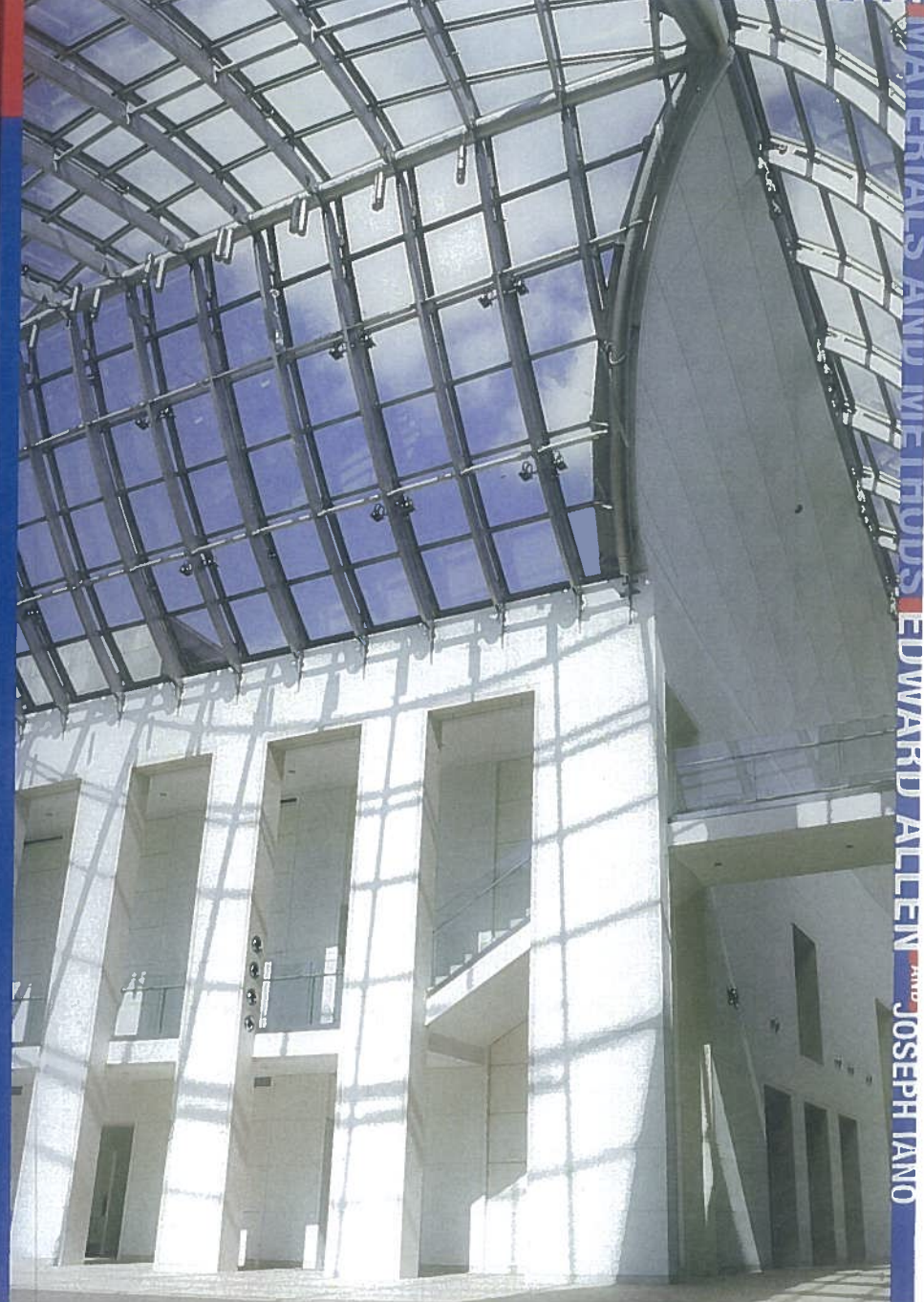
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FUNDAMENTALS OF BUILDING CONSTRUCTION
MATERIALS AND METHODS
FOURTH EDITION

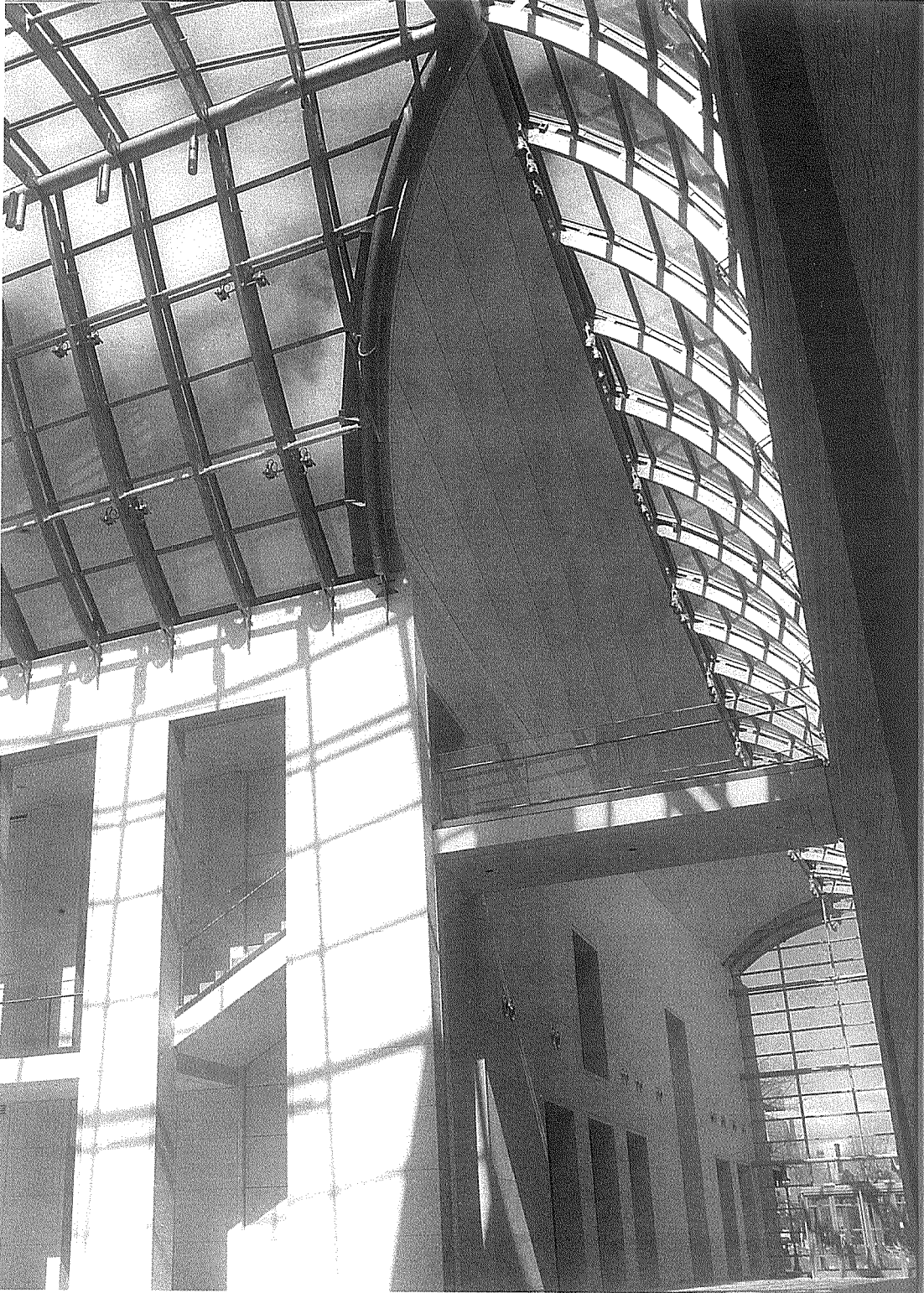


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FOURTH EDITION
FUNDAMENTALS OF BUILDING CONSTRUCTION



MATERIALS AND METHODS
EDWARD ALLEN AND JOSEPH IANO



FUNDAMENTALS OF BUILDING CONSTRUCTION

MATERIALS AND METHODS

FOURTH EDITION

Edward Allen and Joseph Iano



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Published by John Wiley & Sons, Inc., Hoboken, New Jersey
Published simultaneously in Canada

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Library of Congress Cataloging-in-Publication Data:
Allen, Edward, 1938–

Fundamentals of building construction : materials and methods / by
Edward Allen and Joseph Iano.— 4th ed.
p. cm.

Includes bibliographical references and index.
ISBN 0-471-21903-7 (Cloth)

1. Building. 2. Building materials. I. Iano, Joseph. II. Title.

TH145.A417 2004
690—dc21

2003011398

Printed in the United States of America

10 9 8 7 6 5 4 3

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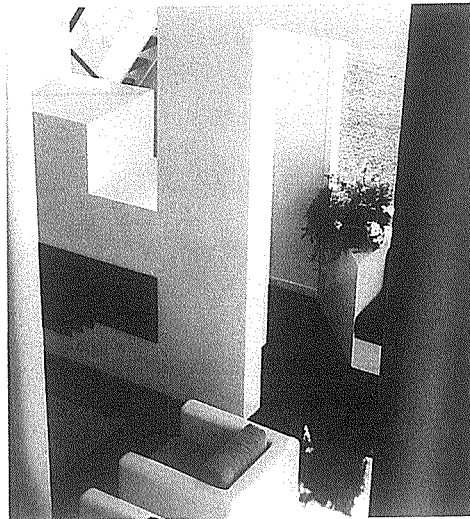
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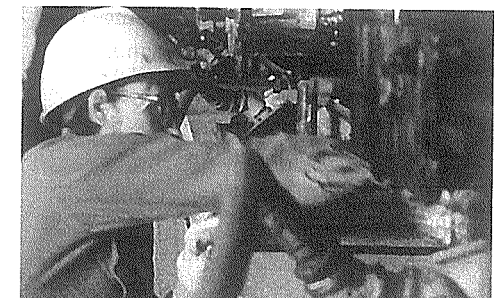
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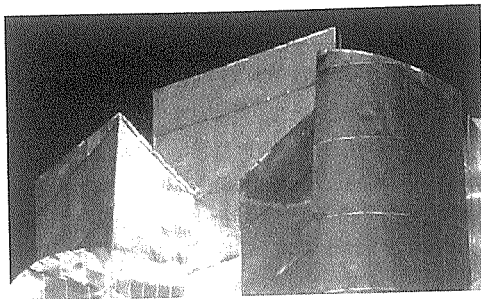
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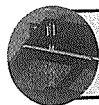
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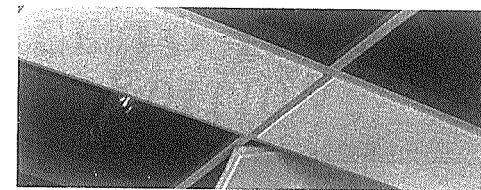


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PREFACE TO THE FOURTH EDITION

It is a special satisfaction for me to introduce the *Fourth Edition* of a work that has been so warmly received by its readers in the previous three editions. This new edition of *Fundamentals of Building Construction* has provided an opportunity to make changes both large and small in response to changes in the field of construction and to suggestions from the students, teachers, and professionals who use the book.

The most important new feature of this edition is the information on sustainability and “green” building that is found in nearly every chapter. A new section in Chapter 1 gives the background for this series and explains why sustainable building practices are essential to our future.

Also new are four illustrated essays, conceived and written by Joseph Iano, entitled “From Concept to Reality.” Each is a brief account of how a group of building professionals made decisions about materials and details for a specific feature of an actual building project. These are intended to help the reader build a conceptual bridge between images and words on the pages of a book and the real-world process of making a building.

Continuing an effort that began with the previous edition, a number of new photorealistic drawings have been added. Most of them replace older ink drawings, but many of them are wholly new.

The World Wide Web has matured to become the major source of information on building products and services. Its advantages are its currency (it is always up to the minute), its immediacy (there is no need to wait for a catalog to find its way through the mail), and its inclusiveness (there is nothing that it does not have). Accordingly, a sampling of web site addresses has been added to the list of references at the end of each chapter. These will serve as points of entry for exploration of the infinite resources that the Web provides.

The introduction of the International Building Code (IBC) as a single model code for the United States and its swift adoption by a majority of states and code jurisdictions provided the impetus for making the IBC the model code upon which this new edition is based.

This book is the centerpiece of an expanding group of information resources for students and teachers. The *Instructor's Manual* is newly revised to correspond with this *Fourth Edition*. Joseph Iano has revised the *Exercises in Building Construction* and its answer key. A new PowerPoint presentation by Professor Dennis Bausman of Clemson University and a new collection of full-color photographs of construction operations by Professor Stephen Diamond of Wentworth Institute of Technology offer, for the first time, a set of lecture presentations and an extensive library of images for use by teachers and students alike. Professor Hitesh Doshi of Ryerson University is the author of animations of construction details and a bank of test questions.

A completely new web site for *Fundamentals of Building Construction* (www.wiley.com/constructioneducation) has been created as the means of distributing these products and offering information on new developments in the world of construction and construction education. This site also gives all users of the book—professionals, teachers, and students—access to its author and publisher. The reader is urged to send a message whenever he or she has a comment or a question.

In addition to these substantive changes, the author has reworked the entire text with two objectives in mind: one is to reflect as accurately as possible the current state of the building industry; the other is to make the narrative as attractive and readable as possible.

I acknowledge with special gratitude the contributions of my gifted colleague Joseph Iano. Joe prepared the drawings for the original edition of this book. His

role has grown with each succeeding edition. His major contribution to this edition is the "Concept to Reality" essays. He also has acted as both source and sounding board for new ideas, and is the principal author of *Exercises in Building Construction*.

My special thanks go to the talented Lon R. Grohs, who prepared the new photorealistic drawings for this edition. I am grateful also for the photographers and construction organizations who furnished new information and illustrations.

Working with the people of John Wiley & Sons, Inc., as always, has been a joy. Preparation of this *Fourth Edition* was initiated under the expert guidance of Amanda Miller, who at that time was a Senior Editor. Upon her promotion, Paul Drougas assumed the role of Editor. His extensive experience in publishing and his attention to every detail, in addition to his good humor when things have gone wrong, have been invaluable to me. Karin Kincheloe, as she has done for the previous editions, applied her magic touch to the graphic design of this volume, and as before, she followed through to design the

layout of every one of its pages. Donna Conte, Senior Production Editor, oversaw the impossibly complex process of producing this book with the calm confidence and sure hand of a consummate professional. Jennifer Ackerman, Assistant Developmental Editor, was instrumental in organizing many facets of the new work, including the developmental review process, editorial development, and the preparation of the new features for the web site.

The teachers, students, and professionals who buy and use this book are ultimately responsible for keeping it in print. Your loyalty and your comments and suggestions are greatly appreciated. Thank you all!

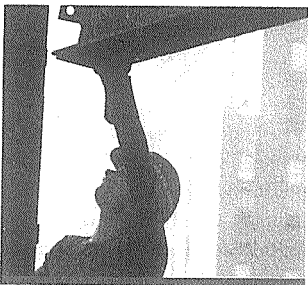
I dedicate this *Fourth Edition* to Dr. Mary M. Allen, my wife and close friend of more than 40 years. Without her perceptive advice, her insights into the educational process, and her constant efforts to protect my time and energies, this book could not have come to fruition.

E. A.
South Natick, Massachusetts

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MAKING BUILDINGS

- Designing Buildings
- Choosing Building Systems:
Constraints
 - Zoning Ordinances
 - Building Codes
 - Other Legal Constraints

- Choosing Building Systems:
Information Resources
 - ASTM, CSA, and ANSI
 - Construction Trade and Professional Associations
 - MasterFormat
- Choosing Building Systems:
The Work of the Design Professional
 - Sustainability
 - Making Choices
 - Recurring Concerns

An ironworker connects a steel wide-flange beam to a column.
(Courtesy of Bethlehem Steel Company)

We build because most human activities cannot take place outdoors. We need shelter from sun, wind, rain, and snow. We need dry, level platforms for our activities. Often we need to stack these platforms to multiply available groundspace. On these platforms, and within our shelter, we need air that is warmer or cooler, more or less humid, than outdoors. We need less light by day, and more by night, than is offered by the natural world. We need services that provide energy, communications, and water, and dispose of wastes. So we gather materials and assemble them into the constructions we call buildings in an attempt to satisfy these needs.

DESIGNING BUILDINGS

A building begins as an idea in someone's mind, a desire for new and ample accommodations for a family, many families, an organization, or an enterprise. For any but the smallest of buildings, the next step for the owner of the prospective building is to engage, either directly or through a hired construction manager, the services of building design professionals. An architect helps to consolidate the owner's ideas about the new building, develops the form of the building, and assembles a group of engineering specialists to help work out concepts and details of foundations, structural support, and mechanical, electrical, and communications services.

This team of designers, working with the owner, then develops the scheme for the building in progressively finer degrees of detail. Drawings and written specifications are produced by the architect-engineer design team to document how the building is to be made and of what. A general contractor is selected, either by negotiation or by competitive bidding. The general contractor hires subcontractors to carry out many specialized portions of the work. The drawings and specifications are submitted to the municipal inspector of buildings, who checks them for conformance with zoning ordinances and building codes before issuing a permit to build. Construction may then begin, with the building inspec-

tor, the architect, and the engineering consultants inspecting the work at frequent intervals to be sure that it is carried out according to plan.

CHOOSING BUILDING SYSTEMS: CONSTRAINTS

Although a building begins as an abstraction, it is built in a world of material realities. The designers of a building—the architects and engineers—work constantly from a knowledge of what is possible and what is not. They are able, on the one hand, to employ any of a limitless palette of building materials and any of a number of structural systems to produce a building of almost any desired form and texture. On the other hand, they are inescapably bound by certain physical limitations: how much land there is with which to work; how heavy a building the soil can support; how long a structural span is feasible; what sorts of materials will perform well in the given environment. They are also constrained by a construction budget and by a complex web of legal restrictions.

Those who work in the building professions need a broad understanding of many things, including people, climate, the physical principles by which buildings work, the technologies available for utilization in buildings, the legal restrictions on buildings, and the contractual arrangements under which buildings are built. This book is concerned pri-

marily with the technologies of construction materials—what the materials are, how they are produced, what their properties are, and how they are crafted into buildings. These must be studied, however, with reference to many other factors that bear on the design of buildings, some of which require explanation here.

Zoning Ordinances

The legal restrictions on buildings begin with local zoning ordinances, which govern the types of activities that may take place on a given piece of land, how much of the land may be covered by the building or buildings, how far buildings must be set back from each of the property lines, how many parking spaces must be provided, how large a total floor area may be constructed, and how tall the building may be. In many cities, the zoning ordinances establish special center-city fire zones in which buildings may be built only of noncombustible materials. Copies of the zoning ordinances for a municipality are available for purchase or reference at the office of the building inspector or the planning department, or they may be consulted at public libraries.

Building Codes

In addition to its zoning ordinances, each local government also regulates building activity by means of a *building code*. The intent of a building code is to protect public health and safety, primarily against building fires, by setting a minimum standard of construction quality.

Most building codes in North America are based on one of several *model building codes*, standardized codes prepared by national organizations of local building code officials. Canada publishes its own model code, the *National Building Code of Canada*. In the United States, building codes are enacted and enforced at the state and local levels. At this writing, more and more local code

jurisdictions throughout the United States are adopting as a model the *International Building Code® (IBC)*, the first unified code in U.S. history, first published in March of 2000. Many jurisdictions, however, still base their codes on three earlier model codes that competed with one another: In the western United States and parts of the Midwest, most codes have been modeled after the *Uniform Building Code (UBC)*. In the East and other areas of the Midwest, the *BOCA National Building Code (BOCA)* has been the model. The *Standard Building Code (SBC)* has been adopted by many southern and southeastern states. The IBC was written and issued by the cooperative efforts of the three organizations that formerly published these competing codes.

The establishment of a single model building code for the United States was welcome news to architects and engineers, who were weary of having to work to different standards in different parts of the country. However, their relief was not to last long, because the National Fire Protection Association, for reasons that are difficult to appreciate, issued the first edition of its own model building code in 2002, raising the possibility that it will be adopted in many code jurisdictions and thereby create a situation even more chaotic than before.

Building-code-related information in this book is based on the *International Building Code (IBC)*. The IBC begins by defining *occupancy groups* for buildings as follows:

- Groups A-1 through A-5 are Assembly occupancies: theaters, auditoriums, lecture halls, night clubs, restaurants, houses of worship, libraries, museums, sports arenas, and so on.
- Group B is Business occupancies: banks, administrative offices, higher-education facilities, police and fire stations, post offices, professional offices, and the like.
- Group E is Educational occupancies: schools for grades K through 12 and day care facilities.
- Group F comprises industrial buildings.
- Groups H-1 through H-5 are various types of High Hazard occupancies in which toxic, combustible, or explosive materials are present.
- Groups I-1 through I-4 are Institutional occupancies in which occupants may not be able to save themselves during a fire or other emergency, such as health care and geriatric facilities and prisons.
- Group M is Mercantile occupancies: stores, markets, service stations, and sales rooms.
- Groups R-1 through R-4 are Residential occupancies, including apartment buildings, dormitories, fraternities and sororities, hotels, one- and two-family dwellings, and assisted-living facilities.
- Group S-1 includes buildings for Storage of hazardous materials, and S-2, low-hazard storage.
- Group U is Utility buildings. It comprises agricultural buildings, carports, greenhouses, sheds, stables, fences, tanks, towers, and other secondary buildings.

The IBC's purpose in establishing occupancy groups is to distinguish various degrees and qualities of need for safety in buildings. A hospital, in which many patients are bedridden and cannot escape a fire under their own power, must be built to a high standard of safety. A warehouse for masonry materials, which are noncombustible, is likely to be occupied by only a few people, all of them able bodied, and can be constructed to a lower standard. An elementary school requires more protection for its occupants than a university building. A theater needs special egress provisions to allow its many patrons to escape quickly, without stampeding, in an emergency.

These definitions of occupancy groups are followed by a set of definitions of *construction types*. At the head of this list (Type I) are highly fire-resistant kinds of construction such as masonry, reinforced concrete, and fire-protected steel. At the foot of it

(Type V) are kinds of construction that are relatively combustible because they are framed with small wood members. In between are a range of construction types with varying levels of resistance to fire.

With occupancy groups and construction types carefully defined, the code proceeds to match the two, setting forth in a table which occupancy groups may be housed in which types of construction, and under what limitations of story height and area per floor. Figure 1.1 is reproduced from the *International Building Code*. It gives the maximum height in stories and the maximum area per floor for every possible combination of occupancy group and construction type. The maximum total floor area of a building under the IBC is three times the maximum area permitted for one floor. If the floor area for a single floor is unlimited, of course, the maximum floor area for the building is also unlimited.

This table concentrates a great deal of useful information into a very small space. A designer may enter it with a particular occupancy group in mind—an electronics plant, for example—and find out very quickly what types of construction will be permitted and what shape the plant may take. Under the IBC, an electronics plant belongs to Occupancy Group F-1, Factory, Moderate-Hazard Occupancy. Reading across the chart from left to right, we find immediately that this factory may be built to any desired size, without limit, using Type IA construction.

Type IA construction is defined in nearby tables in the IBC, one of which is reproduced here as Figure 1.2. Looking down the columns of this table under Type IA construction, we find a listing of the required *fire resistance ratings*, measured in hours, of the various parts of either a Type IA or a Type IB building. In a Type IA building, for example, we find on the first line that columns, girders, and trusses must be rated at 3 hours. The second line mandates a 3-hour resistance also for *bearing walls*,

TABLE 503
ALLOWABLE HEIGHT AND BUILDING AREAS
 Height limitations shown as stories and feet above grade plane.
 Area limitations as determined by the definition of "Area, building," per floor.

GROUP	HGT(feet)	TYPE OF CONSTRUCTION									
		TYPE I		TYPE II		TYPE III		TYPE IV	TYPE V		
		A	B	A	B	A	B	HT	A	B	
	UL	UL	160	65	55	65	55	65	50	40	
A-1	S	UL	5	3	2	3	2	3	2	1	
	A	UL	UL	15,500	8,500	14,000	8,500	15,000	11,500	5,500	
A-2	S	UL	11	3	2	3	2	3	2	1	
	A	UL	UL	15,500	9,500	14,000	9,500	15,000	11,500	6,000	
A-3	S	UL	11	3	2	3	2	3	2	1	
	A	UL	UL	15,500	9,500	14,000	9,500	15,000	11,500	6,000	
A-4	S	UL	11	3	2	3	2	3	2	1	
	A	UL	UL	15,500	9,500	14,000	9,500	15,000	11,500	6,000	
A-5	S	UL	UL	UL	UL	UL	UL	UL	UL	UL	
	A	UL	UL	UL	UL	UL	UL	UL	UL	UL	
B	S	UL	11	5	4	5	4	5	3	2	
	A	UL	UL	37,500	23,000	28,500	19,000	36,000	18,000	9,000	
E	S	UL	5	3	2	3	2	3	1	1	
	A	UL	UL	26,500	14,500	23,500	14,500	25,500	18,500	9,500	
F-1	S	UL	11	4	2	3	2	4	2	1	
	A	UL	UL	25,000	15,500	19,000	12,000	33,500	14,000	8,500	
F-2	S	UL	11	5	3	4	3	5	3	2	
	A	UL	UL	37,500	23,000	28,500	18,000	50,500	21,000	13,000	
H-1	S	1	1	1	1	1	1	1	1	NP	
	A	21,000	16,500	11,000	7,000	9,500	7,000	10,500	7,500	NP	
H-2	S	UL	3	2	1	2	1	2	1	1	
	A	21,000	16,500	11,000	7,000	9,500	7,000	10,500	7,500	3,000	
H-3	S	UL	6	4	2	4	2	4	2	1	
	A	UL	60,000	26,500	14,000	17,500	13,000	25,500	10,000	5,000	
H-4	S	UL	7	5	3	5	3	5	3	2	
	A	UL	UL	37,500	17,500	28,500	17,500	36,000	18,000	6,500	
H-5	S	3	3	3	3	3	3	3	3	2	
	A	UL	UL	37,500	23,000	28,500	19,000	36,000	18,000	9,000	
I-1	S	UL	9	4	3	4	3	4	3	2	
	A	UL	55,000	19,000	10,000	16,500	10,000	18,000	10,500	4,500	
I-2	S	UL	4	2	1	1	Np	1	1	NP	
	A	UL	UL	15,000	11,000	12,000	Np	12,000	9,500	NP	
I-3	S	UL	4	2	1	2	1	2	2	1	
	A	UL	UL	15,000	11,000	10,500	7,500	12,000	7,500	5,000	
I-4	S	UL	5	3	2	3	2	3	1	1	
	A	UL	60,500	26,500	13,000	23,500	13,000	25,500	18,500	9,000	
M	S	UL	11	4	4	4	4	4	3	1	
	A	UL	UL	21,500	12,500	18,500	12,500	20,500	14,000	9,000	
R-1	S	UL	11	4	4	4	4	4	3	2	
	A	UL	UL	24,000	16,000	24,000	16,000	20,500	12,000	7,000	
R-2 ^a	S	UL	11	4	4	4	4	4	3	2	
	A	UL	UL	24,000	16,000	24,000	16,000	20,500	12,000	7,000	
R-3 ^a	S	UL	11	4	4	4	4	4	3	3	
	A	UL	UL	UL	UL	UL	UL	UL	UL	UL	
R-4	S	UL	11	4	4	4	4	4	3	2	
	A	UL	UL	24,000	16,000	24,000	16,000	20,500	12,000	7,000	
S-1	S	UL	11	4	3	3	3	4	3	1	
	A	UL	48,000	26,000	17,500	26,000	17,500	25,500	14,000	9,000	
S-2	S	UL	11	5	4	4	4	5	4	2	
	A	UL	79,000	39,000	26,000	39,000	26,000	38,500	21,000	13,500	
U	S	UL	5	4	2	3	2	4	2	1	
	A	UL	35,500	19,000	8,500	14,000	8,500	18,000	9,000	5,500	

For SI: 1 foot = 304.8 mm, 1 square foot = 0.0929 m².

UL = Unlimited

a. As applicable in Section 101.2.

FIGURE 1.1

Height and area limitations of buildings of various types of construction, as defined in the 2000 International Building Code. (Copyright 2000, International Code Council, Inc., Falls Church, Virginia. 2000 International Building Code®. Reprinted with permission of the author. All rights reserved)

FIGURE 1.2

Fire resistance of structural elements, as required by the 2000 International Building Code. (Copyright 2000, International Code Council, Inc., Falls Church, Virginia. 2000 International Code®. Reprinted with permission of the author. All rights reserved)

walls that serve to carry floors or roofs above. *Nonbearing walls* or *partitions*, which carry no load from above, are listed in the third line, which refers to Table 602, which gives fire resistance rating requirements based on the building's distance from other buildings. (Table 602 is included in Figure 1.2.) Floor construction and roof

TABLE 601
FIRE-RESISTANCE RATING REQUIREMENTS FOR BUILDING ELEMENTS (hours)

BUILDING ELEMENT	TYPE I		TYPE II		TYPE III		TYPE IV	TYPE V	
	A	B	A ^d	B	A	B	HT	A ^d	B
Structural frame ^a Including columns, girders, trusses	3 ^b	2 ^b	1	0	1	0	HT	1	0
Bearing walls Exterior ^d Interior	3 3 ^b	2 2 ^b	1 1	0 0	2 1	2 0	2 1/HT	1 1	0 0
Nonbearing walls and partitions Exterior Interior ^e	See Table 602 See Section 602								
Floor construction Including supporting beams and joists	2	2	1	0	1	0	HT	1	0
Roof construction Including supporting beams and joists	1 1/2 ^c	1 ^c	1 ^c	0	1 ^c	0	HT	1 ^c	0

For SI: 1 foot = 304.8 mm.

- The structural frame shall be considered to be the columns and the girders, beams, trusses and spandrels having direct connections to the columns and bracing members designed to carry gravity loads. The members of floor or roof panels which have no connection to the columns shall be considered secondary members and not a part of the structural frame.
- Roof supports: Fire-resistance ratings of structural frame and bearing walls are permitted to be reduced by 1 hour where supporting a roof only.
1. Except in Factory-Industrial (F-I), Hazardous (H), Mercantile (M) and Moderate-Hazard Storage (S-1) occupancies, fire protection of structural members shall not be required, including protection of roof framing and decking where every part of the roof construction is 20 feet or more above any floor immediately below. Fire-retardant-treated wood members shall be allowed to be used for such unprotected members.
2. In all occupancies, heavy timber shall be allowed where a 1-hour or less fire-resistance rating is required.
3. In Type I and Type II construction, fire-retardant-treated wood shall be allowed in buildings not over two stories including girders and trusses as part of the roof construction.
4. An approved automatic sprinkler system in accordance with Section 903.3.1.1 shall be allowed to be substituted for 1-hour fire-resistance-rated construction, provided such system is not otherwise required by other provisions of the code or used for an allowable area increase in accordance with Section 506.3 or an allowable height increase in accordance with Section 504.2. The 1-hour substitution for the fire resistance of exterior walls shall not be permitted.
- For interior nonbearing partitions in Type IV construction, also see Section 602.4.6.
- Not less than the fire-resistance rating based on fire separation distance (see Table 602).

TABLE 602
FIRE-RESISTANCE RATING REQUIREMENTS FOR EXTERIOR WALLS BASED ON FIRE SEPARATION DISTANCE^a

FIRE SEPARATION DISTANCE (feet)	TYPE OF CONSTRUCTION	GROUP H	GROUP F-1, M, S-1	GROUP A, B, E, F-2, I, R ^b , S-2, U
< 5 ^c	All	3	2	1
≥ 5	IA	3	2	1
< 10	Others	2	1	1
≥ 10	IA, IB	2	1	1
< 30	IIB, VB	1	0	0
	Others	1	1	1
≥ 30	All	0	0	0

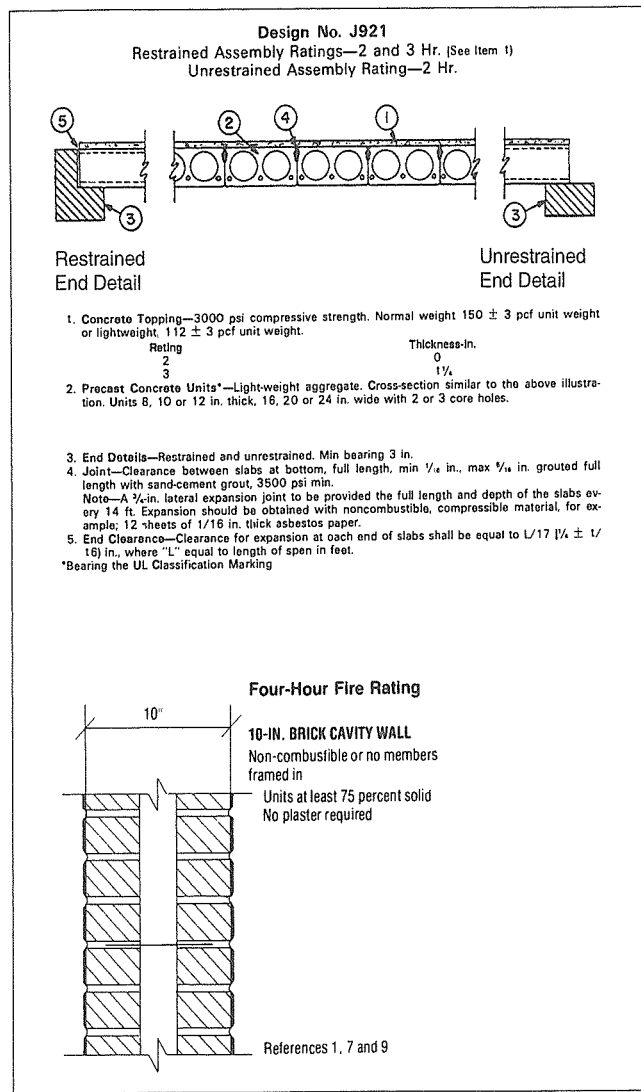
For SI: 1 foot = 304.8 mm.

a. Load-bearing exterior walls shall also comply with the fire-resistance rating requirements of Table 601.

b. Group R-3 and Group U when used as accessory to Group R-3, as applicable in Section 101.2 shall not be required to have a fire-resistance rating where fire separation distance is 3 feet or more.

c. See Section 503.2 for party walls.

FIGURE 1.3
Examples of fire resistance ratings for concrete and masonry structural elements. The upper detail, taken from the Underwriters Laboratories Fire Resistance Directory, is for a precast concrete hollow-core plank floor with poured concrete topping. "Restrained" and "unrestrained" refer to whether or not the floor is prevented from expanding longitudinally when exposed to the heat of a fire. The lower detail is from literature published by the Brick Institute of America. (Reprinted by permission of Underwriters Laboratories Inc. and Brick Institute of America, respectively)



construction standards are defined in the last two lines of Table 601.

Looking across Table 601 in Figure 1.2, we can see that fire resistance rating requirements are highest for Type IA construction, decrease to 1 hour for Type VA, and finally to zero for Type VB.

Fire resistance ratings of many common construction components and assemblies are found in Section 7.19 of the IBC. Ratings for many more assemblies are tabulated in a

variety of catalogs and handbooks issued by building material manufacturers, construction trade associations, and organizations concerned with fire protection of buildings. In each case, the ratings are derived from full-scale laboratory fire tests of building components carried out in accordance with Standard E119 of the American Society for Testing and Materials, to assure uniformity of results. (This fire test is described more fully in Chapter 22 of this

book.) Figures 1.3–1.5 reproduce small sections of tables from catalogs and handbooks to illustrate how this type of information is presented.

It is not possible in this volume to reproduce a comprehensive listing of fire resistance ratings for every type of building component, but what can be said in a very general way (and with many exceptions) is that the higher the degree of fire resistance, the higher the cost. In general, therefore, buildings are built with the least

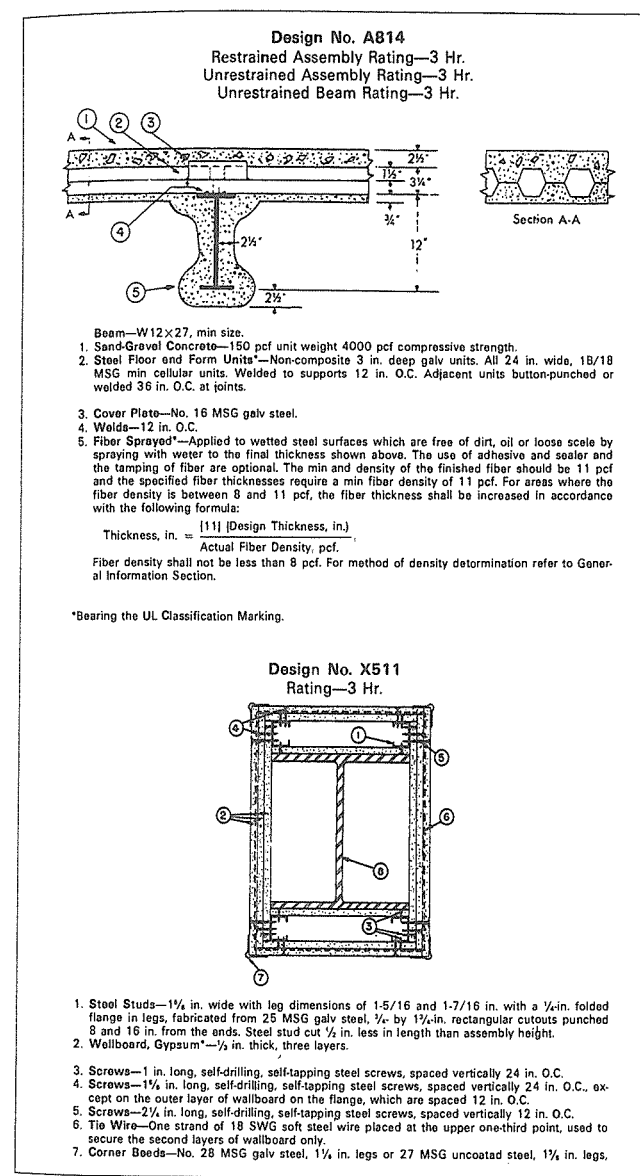


FIGURE 1.4
Fire resistance ratings for a steel floor structure and column, respectively, taken from the Underwriters Laboratories Fire Resistance Directory. (Reprinted by permission of Underwriters Laboratories Inc.)

FIGURE 1.5
A sample of fire resistance ratings published by the Gypsum Association, in this case for an interior partition. (Courtesy of Gypsum Association)

Fire Rating	Sound Rating STC	GA File No.	DETAILED DESCRIPTION	SKETCH AND DESIGN DATA	
				Fire	Sound
1 HR	30 to 34	WP 3620	Construction Type: Gypsum-Veneer Base, Veneer Plaster, Wood Studs One layer 1/2" type X gypsum veneer base applied at right angles to each side of 2 x 4 wood studs 16" o.c. with 5d etched nails, 1 1/4" long, 0.099" shank, 1/4" heads, 8" o.c. Minimum 1/16" gypsum-veneer plaster over each face. Stagger vertical joints 16" and horizontal joints each side 12". Sound tested without veneer plaster. (LB)		
				Thickness: 4 7/8" Approx. Weight: 7 psf Fire Test: UC, 1-12-66 Sound Test: G & H IBI-35FT. 5-26-64	

level of fire resistance that is permitted by the applicable building code. The hypothetical electronics plant could be built using Type IA construction, but does it really need to be constructed to this high standard?

Let us suppose that the owners want the electronics plant to be a two-story building with 20,000 square feet on each floor. The table in Figure 1.1 makes it clear that it can be built of Type IB and Type IIA construction, but not of Type IIB, which permits only 15,500 square feet per floor. It can be built of Type IIIA or IV construction, but not of Type IIIB, VA, or VB.

Other factors come into play in these computations. If a building is protected throughout by an approved, fully automatic sprinkler system for suppression of fires, the IBC provides that the tabulated area may be quadrupled for a single-story building, and tripled for multistory buildings. A one-story increase in allowable height is also granted for most occupancies if a sprinkler system is installed. If the two-story, 20,000-square-foot electronics plant that we have been considering is provided with an approved automatic sprinkler system, a bit of arithmetic will show that it can be built of any construction type shown in Figure 1.1.

If more than a quarter of the building's perimeter walls face public ways or open spaces, an increase in area is granted in accordance with a simple formula. Additionally, if a building is divided by fire walls having the fire resistance ratings specified in another table (Figure 1.6), each portion of the building that is separated from the remainder of the building by fire walls may be considered as a separate building for purposes of computing its allowable area, which effectively permits the architect to create a building many times larger than Figure 1.1 would indicate.

The IBC also establishes standards for natural light; ventilation; means of emergency egress; structural design; floor, wall, ceiling, and

GROUP	FIRE-RESISTANCE RATING (hours)
A, B, E, H-4, I, R-1, R-2, U	3 ^a
F-1, H-3 ^b , H-5, M, S-1	3
H-1, H-2	4 ^b
F-2, S-2, R-3, R-4	2

a. Walls shall be not less than 2-hour fire-resistance rated where separating buildings of Type II or V construction.
b. For Group H-1, H-2 or H-3 buildings, also see Sections 415.4 and 415.5.

FIGURE 1.6

Fire resistance requirements for fire walls, as required by the 2000 International Building Code. (Copyright 2000, International Code Council, Inc., Falls Church, Virginia. 2000 International Code®. Reprinted with permission of the author. All rights reserved)

roof construction; chimney construction; fire protection systems; accessibility of the building to disabled persons; energy efficiency; and many other important factors.

The building code is not the only code with which a new building must comply. There are also health codes, fire codes, plumbing codes, and electrical codes in force in most communities. Some of these are locally written, but most are based on model national codes.

Other Legal Constraints

Other types of legal restrictions must also be observed in the design and construction of buildings. Access standards regulate the design of

entrances, stairs, doorways, elevators, and toilet facilities to assure that they are accessible by physically handicapped members of the population. The *Americans with Disabilities Act* (ADA) makes accessibility to buildings a civil right of all Americans. The U.S. *Occupational Safety and Health Act* (OSHA) controls the design of workplaces to minimize hazards to the health and safety of workers. OSHA sets safety standards under which a building must be constructed and also has an important effect on the design of industrial and commercial buildings. Many states have established comprehensive standards of energy efficiency for buildings; these affect primarily a designer's choices of thermal insulation, windows, and heating and cooling systems. Many energy codes go deeply into details of construction with respect to thermal resistance and airtightness. An increasing number of states have limitations on the amount of volatile organic compounds such as solvents for paints and construction adhesives that building products can release into the atmosphere. States and localities have conservation laws that protect wetlands and other environmentally sensitive areas from encroachment by buildings. Fire

insurance companies exert a major influence on construction standards through their testing and certification organizations (Underwriters Laboratories and Factory Mutual, for example) and through their rate structures for building insurance coverage, which offer strong financial incentives for more fire-resistant construction. Building contractors and construction labor unions also have standards, both formal and informal, that affect the ways in which buildings are built. Unions have work rules and safety rules that must be observed; contractors have particular types of equipment, certain kinds of skills, and customary ways of going about things. All of these vary significantly from one place to another.

CHOOSING BUILDING SYSTEMS: INFORMATION RESOURCES

The tasks of the architect and the engineer would be impossible without the support of dozens of organizations that produce and disseminate information on materials and methods of construction. Several organizations and types of organizations whose work has the most direct impact on day-to-day building design and construction operations are discussed in the sections that follow.

ASTM, CSA, and ANSI

The *American Society for Testing and Materials* (ASTM) establishes standard specifications for commonly used materials of construction. These specifications are accepted throughout the United States and are generally referred to by number (ASTM C150, for example, is a specification for portland cement). These numbers are frequently used in construction specifications for specific buildings as precise shorthand designations for the quality of material

that is required. Throughout this book, ASTM specification numbers will be provided for the major building materials. Should you wish to examine the contents of any ASTM specification, they can be found in the ASTM publication listed at the end of this chapter. In Canada, corresponding standards are set by the *Canadian Standards Association* (CSA).

The *American National Standards Institute* (ANSI) is an organization that develops standards for many industrial products, such as aluminum windows and many of the mechanical components of buildings. Some government agencies, most notably the U.S. Department of Commerce, also establish standards for certain building products. For the most part, the standards set by the various organizations are complementary and do not overlap or conflict.

Construction Trade and Professional Associations

Building professionals, building materials manufacturers, and building contractors have formed a large number of organizations that work toward the development of technical standards and the dissemination of information with relation to their respective fields of interest. The *Construction Specifications Institute* (CSI), whose *MasterFormat*™ standard is described in the following section, is one example. It is composed both of independent building professionals, such as architects and engineers, and of members from industry. The Western Wood Products Association, to choose an example from among a hundred or more trade associations, is made up of producers of lumber and wood products. It carries out programs of research on wood products, establishes uniform standards of product quality, certifies mills and products that conform to its standards, and publishes authoritative technical literature concerning the use of lumber and related products. Associations with a similar range of

activities exist for virtually every material and product used in building. All of them publish technical data and maintain web sites relating to their fields of interest, and many of these publications are indispensable references for the architect or engineer. A considerable number are incorporated by reference into various building codes and standards. Selected publications from professional and trade associations are identified in the reference lists at the ends of the chapters in this book. The reader is encouraged to obtain these publications and to request complete publication lists from the various organizations.

Web sites are also given for many of these organizations. These often contain an astonishing amount of technical information. Most can be used as a means of ordering publications, and many sites offer the possibility of downloading publications directly.

The World Wide Web is a rich source of information about materials and construction. It is infinite in scope and constantly changing, making it impossible to provide definitive lists of web sites on a topic. At the end of each chapter, a few web sites of interest are presented. These can serve as points of entry from which the reader may link to other sites and make his or her own exploration on any topic of interest.

MasterFormat

The Construction Specifications Institute of the United States and its Canadian counterpart, *Construction Specifications Canada* (CSC), have evolved over a period of many years a standard outline called *MasterFormat* for organizing information about construction materials and components. MasterFormat is used as the outline for construction specifications for nearly all large construction projects in the two countries. It also forms the basis on which trade associations' and manufacturers' technical

... the architect should have construction at least as much at his fingers' ends as a thinker his grammar.

Le Corbusier, *Towards a New Architecture*, 1927

literature is cataloged and filed. Its 16 primary divisions are as follows:

- Division 1 General Requirements
- Division 2 Site Work
- Division 3 Concrete
- Division 4 Masonry
- Division 5 Metals
- Division 6 Wood and Plastics
- Division 7 Thermal and Moisture Protection
- Division 8 Doors and Windows
- Division 9 Finishes
- Division 10 Specialties
- Division 11 Equipment
- Division 12 Furnishings
- Division 13 Special Construction
- Division 14 Conveying Systems
- Division 15 Mechanical
- Division 16 Electrical

Within these broad divisions, several levels of subdivision are established to allow the user to reach any desired degree of detail. A five-digit code, in which the first two digits correspond to the division numbers above, gives the exact reference to any category of information. Within Division 5, Metals, for example, some standard reference codes are

- 05120 Structural Steel
- 05210 Steel Joists
- 05310 Steel Deck
- 05400 Cold-Formed Metal Framing
- 05725 Ornamental Metal Castings

Almost every chapter of this book gives the major MasterFormat designations for the information presented, to help the reader know where to look in construction specifications and in the technical literature for further information. The full MasterFormat system is contained in the volume referenced at the end of this chapter. At the time of publication of this book, CSI is beginning the development of a new, expanded version

of MasterFormat that will broaden its usefulness and adapt it to the full life cycle of constructed projects.

CHOOSING BUILDING SYSTEMS: THE WORK OF THE DESIGN PROFESSIONAL

The designers of a building must make many choices before its design is complete and ready for construction. In making these choices, they confront several basic questions:

- What will give the required functional performance?
- What will give the desired aesthetic result?
- What is possible legally?
- What is most economical?
- How can we build in a sustainable manner?

This book examines primarily the first of these questions, the functional performance of the materials and methods of building construction most commonly employed in North America. Reference is made constantly, however, to the other four questions, and the reader should always have them uppermost in mind. The last question, which concerns sustainability, deserves further explanation.

Sustainability

In constructing and occupying buildings, we expend vast quantities of the earth's resources and generate a significant portion of the earth's environmental pollution. According to Worldwatch Institute estimates, buildings consume at least 40 percent of the energy utilized in the world each year and, in so doing, generate one-third of the carbon dioxide and two-fifths of the acid-rain-causing compounds that are released into the atmosphere. Buildings in the United States use about one-sixth of total freshwater flow and a quarter of har-

vested wood. Buildings emit half of the chlorinated fluorocarbons that escape into the atmosphere to degrade the protective ozone layer around the earth. Construction waste comprises 40 percent of landfill material. In short, buildings are responsible for many forms of environmental degradation that place an increasing burden on the earth's resources and jeopardize the future of the building industry and the health and welfare of humanity itself. Thus, it has become increasingly urgent that we learn to build in a sustainable manner.

Sustainability may be defined as **meeting the needs of the present generation without compromising the ability of future generations to meet their needs.** By consuming fossil fuels and other nonrenewable resources, by building in sprawling urban patterns that cover extensive areas of prime agricultural land, by using wood from forests that are not replanted, by allowing topsoil to be eroded by wind and water, and by generating substances that pollute water, soil, and air, we have been building in a manner that will make it increasingly difficult for our children and grandchildren to meet their needs for buildings and healthy lives.

On the other hand, if we reduce building energy usage and utilize sunlight and wind as energy sources for our buildings, we avoid depletion of fossil fuels. If we reuse existing buildings imaginatively and arrange our new buildings in compact patterns on land of marginal value, we minimize the waste of valuable land. If we harvest wood from forests that are managed in such a way that they can supply wood at a sustained level for the foreseeable future, we maintain wood construction as a viable option for centuries to come. If we protect soil and water through sound design and construction practices, we retain these irreplaceable resources for our successors. If we systematically reduce and eliminate the various forms of pollution emitted in the processes of producing and operating buildings, we keep the environment clean in

perpetuity. It is often possible to do these things without increasing the monetary costs of constructing and operating buildings, and in some cases actually to reduce these costs.

Realization of these goals is dependent on our awareness of the environmental problems created by building activities, knowledge of how to avoid these problems, and skill in designing and constructing buildings that harness this knowledge. Sustainable design and construction, also called "*green*" building, is steadily becoming the goal of more and more building owners, architectural and engineering firms, contractors, and building operators, among them some of the largest organizations in each field.

Sustainability must be addressed on a life-cycle basis, from the origins of the materials for a building, through the manufacture and installation of these materials and their useful lifetime in the building, to their eventual disposal when the building's life is ended. Each step in this life cycle raises questions of sustainability.

Origin and Manufacture of Materials for a Building

Are the raw materials for a building plentiful or rare? Are they renewable or nonrenewable? How much of the content of a material is recycled from other uses? How much energy is expended in obtaining and manufacturing the material, and how much water? What pollutants are discharged into air, water, and soil as a result of these acts? What wastes are created? Can these wastes be converted to useful products?

Construction of the Building

How much energy is expended in transporting a material from its origins to the building site, and what pollutants are generated? How much energy and water are consumed on the building site to put the material in place? What pollutants are associated with the installation of this material into the building? What wastes

Go into the field where you can see the machines and methods at work that make the modern buildings, or stay in construction direct and simple until you can work naturally into building-design from the nature of construction.

Frank Lloyd Wright, *To the Young Man in Architecture*, 1931

are generated, and how much of them can be recycled?

Use and Maintenance of the Building

How much energy and water does the building use over its lifetime as a consequence of using a particular material? What problems of indoor air quality are caused by this material? How much maintenance does a material require, and how long will it last? Can it be recycled? Does the material have particular problems with respect to fire, such as being easily ignited, burning fiercely, or giving off toxic smoke? How much energy and time are consumed in maintaining the material? Does its maintenance involve use of toxic chemicals?

Demolition of the Building

What planning and design strategies can be used to extend the useful life of buildings, thereby forestalling resource-intensive demolition and construction of new buildings? When demolition is inevitable, how will the building be demolished and disposed of, and will any part of this process cause pollution of air, water, or soil? Can demolished materials be recycled into new construction or diverted for other uses rather than disposed of as wastes?

One widely accepted method for keeping track of the sustainability of a building's design is the LEED™ sys-

tem of evaluation, which was developed by the U.S. Green Building Council (Figure 1.7). LEED stands for "Leadership in Energy and Environmental Design." The LEED checklist provides a revealing insight into the breadth and depth of the measures that are needed to build sustainably. The Green Building Council carries on a program of certifying buildings for compliance with LEED guidelines. Architects, engineers, developers, building contractors, and building owners may use this program to document and certify their efforts to build sustainable buildings.

A special sidebar in nearly every chapter of this book explores the major issues of sustainability that relate to the materials and methods discussed in that chapter. These will be helpful in weighing the environmental costs of one material against those of another, and in learning how to build in such a way that we preserve for future generations the ability to meet their building needs in a reasonable and economical manner.

Ultimately, the model for sustainable design is nature itself. Nature works in cyclical processes that are self-sustaining and waste nothing. More and more building professionals are learning to create buildings that work more nearly as nature does, in order to leave to our descendants a stock of buildings, a body of knowledge, an abundant supply of raw materials for building, and a clean environment that will enable them to live comfortably and responsibly and to pass these blessings on to their descendants in a never-ending succession.

There are many organizations whose mission is to raise our awareness and provide the knowledge that we need to build sustainably. The Web addresses of some of these are listed at the end of this chapter.

Making Choices

The chapters that follow describe many alternative ways of doing

FIGURE 1-7
The LEED Registered Project
Checklist, Version 2.1. (Courtesy of
U.S. Green Building Council)

LEED Version 2.1 Registered Project Checklist		Project Name	LEED Project #
Sustainable Sites 14 Points			
Prereq 1	Erosion & Sedimentation Control	Required	
Credit 1.1	Site Selection		
Credit 2	Urban Redevelopment		
Credit 3	Brownfield Redevelopment		
Credit 4.1	Alternative Transportation, Public Transportation Access		
Credit 4.2	Alternative Transportation, Bicycle Storage & Changing Rooms		
Credit 4.3	Alternative Transportation, Alternative Fuel Vehicles		
Credit 4.4	Alternative Transportation, Parking Capacity and Carpooling		
Credit 5.1	Reduced Site Disturbance, Protect or Restore Open Space		
Credit 5.2	Reduced Site Disturbance, Development Footprint		
Credit 6.1	Stormwater Management, Rate and Quantity		
Credit 6.2	Stormwater Management, Treatment		
Credit 7.1	Landscape & Exterior Design to Reduce Heat Islands, Non-Roof		
Credit 7.2	Landscape & Exterior Design to Reduce Heat Islands, Roof		
Credit 8	Light Pollution Reduction		
Water Efficiency 5 Points			
Credit 1.1	Water Efficient Landscaping, Reduce by 50%		
Credit 1.2	Water Efficient Landscaping, No Potable Use or No Irrigation		
Credit 2	Innovative Wastewater Technologies		
Credit 3.1	Water Use Reduction, 20% Reduction		
Credit 3.2	Water Use Reduction, 30% Reduction		
Energy & Atmosphere 17 Points			
Prereq 1	Fundamental Building Systems Commissioning	Required	
Prereq 2	Minimum Energy Performance	Required	
Prereq 3	CFC Reduction in HVAC&R Equipment	Required	
Credit 1	Optimize Energy Performance	1 to 10	
Credit 2.1	Renewable Energy, 5%		
Credit 2.2	Renewable Energy, 10%		
Credit 2.3	Renewable Energy, 20%		
Credit 3	Additional Commissioning		
Credit 4	Ozone Depletion		
Credit 5	Measurement & Verification		
Credit 6	Green Power		

U.S. Green Building Council LEED Checklist LEED™ Green Building Rating System 2.1

LEED Version 2.1 Registered Project Checklist		Project Name	LEED Project #
Materials & Resources 13 Points			
Prereq 1	Storage & Collection of Recyclables	Required	
Credit 1.1	Building Reuse, Maintain 75% of Existing Shell		
Credit 1.2	Building Reuse, Maintain 100% of Shell		
Credit 1.3	Building Reuse, Maintain 100% Shell & 50% Non-Shell		
Credit 2.1	Construction Waste Management, Divert 50%		
Credit 2.2	Construction Waste Management, Divert 75%		
Credit 3.1	Resource Reuse, Specify 5%		
Credit 3.2	Resource Reuse, Specify 10%		
Credit 4.1	Recycled Content, Specify 5% (post-consumer + ... post-industrial)		
Credit 4.2	Recycled Content, Specify 10% (post-consumer + ... post-industrial)		
Credit 5.1	Local/Regional Materials, 20% Manufactured Locally		
Credit 5.2	Local/Regional Materials, of 20% Above, 50% Harvested Locally		
Credit 6	Rapidly Renewable Materials		
Credit 7	Certified Wood		
Indoor Environmental Quality 15 Points			
Prereq 1	Minimum IAQ Performance	Required	
Prereq 2	Environmental Tobacco Smoke (ETS) Control	Required	
Credit 1	Carbon Dioxide (CO ₂) Monitoring		
Credit 2	Ventilation Effectiveness		
Credit 3.1	Construction IAQ Management Plan, During Construction		
Credit 3.2	Construction IAQ Management Plan, Before Occupancy		
Credit 4.1	Low-Emitting Materials, Adhesives & Sealants		
Credit 4.2	Low-Emitting Materials, Paints		
Credit 4.3	Low-Emitting Materials, Carpet		
Credit 4.4	Low-Emitting Materials, Composite Wood & Agglomerate		
Credit 5	Indoor Chemical & Pollutant Source Control		
Credit 6.1	Controllability of Systems, Perimeter		
Credit 6.2	Controllability of Systems, Non-Perimeter		
Credit 7.1	Thermal Comfort, Comply with ASHRAE 55-1992		
Credit 7.2	Thermal Comfort, Permanent Monitoring System		
Credit 8.1	Daylight & Views, Daylight 75% of Spaces		
Credit 8.2	Daylight & Views, Views for 90% of Spaces		
Innovation & Design Process 5 Points			
Credit 1.1	Innovation in Design: Provide Specific Title		
Credit 1.2	Innovation in Design: Provide Specific Title		
Credit 1.3	Innovation in Design: Provide Specific Title		
Credit 1.4	Innovation in Design: Provide Specific Title		
Credit 2	LEED™ Accredited Professional		
Project Totals (pre-certification estimate) 69 Points			
Certified 26-52 points Silver 33-38 points Gold 39-51 points Platinum 52-69 points			

things: different structural systems, different systems of enclosure, different systems of interior finish. Each system has characteristics that distinguish it from the alternatives. Sometimes a system is distinguished chiefly by its visual qualities, as one might acknowledge in choosing one type of granite over another, one color of paint over another, or one tile pattern over another. However, visual distinctions can extend beyond surface qualities; a designer may prefer the massive appearance of a masonry bearing wall building to the slender look of an exposed steel frame on one project, yet would choose the steel for another building whose situ-

ation is different. Again, one may choose for purely functional reasons, as in selecting terrazzo flooring instead of carpet or wood in a restaurant kitchen. One could choose on purely technical grounds, as, for example, in electing to posttension a long concrete beam rather than merely to reinforce it. A designer is often forced into a particular choice by some of the legal constraints identified earlier in this chapter. A choice is often influenced by considerations of sustainability. And frequently the selection is made on purely economic grounds. The economic criterion can mean any of several things: Sometimes one system is chosen over

another because its first cost is less; sometimes the entire *life-cycle costs* of competing systems are compared by means of formulas that include first cost, maintenance cost, energy consumption cost (if any), the useful lifetime and replacement cost of the system, and interest rates on invested money; and, finally, a system may be chosen because there is keen competition among local suppliers and/or installers that keeps the price at the lowest possible level. This is often a reason to specify a very standard type of roofing material, for example, that can be furnished and installed by any of a number of companies, instead of a new system that is theoretically bet-

ter from a functional standpoint, but can only be furnished by a single company that has the new equipment and skills required to install it.

One cannot gain all the knowledge needed to make such decisions from a textbook. It is incumbent upon the reader to go far beyond what can be presented here—to other books, to catalogs, to trade publications, to professional periodicals, and especially to the design office, the workshop, and the building site. There is no other way to gain much of the required information than to get involved in the art and business of building. One must learn how materials feel in the hand; how they look in

a building; how they are manufactured, worked, and put in place; how they perform in service; how they deteriorate with time. One must become familiar with the people and organizations that produce buildings—the architects, engineers, materials suppliers, contractors, subcontractors, workers, inspectors, managers, and building owners—and learn to understand their respective methods, problems, and points of view. In the meantime, this long and hopefully enjoyable process of education in the materials and methods of building construction can begin with the information presented in the chapters that follow.

Recurring Concerns

Certain themes are woven throughout this book and surface again and again in different, often widely varying contexts. These represent a set of concerns that fall into two broad categories: one that has to do with building performance and one that has to do with building construction.

The performance concerns relate to the inescapable problems that must be confronted in every building: fire; building movement of every kind, including foundation settlement, structural deflections, and expansion and contraction due to changes in temperature and humidity; heat flow through building assemblies; water vapor migration and condensation; water leakage; acoustical privacy; deterioration, cleanliness, and building maintenance.

The construction concerns are associated with the everyday problems of getting a building built safely, on time, within budget, and to the required standard of quality: division of work between the shop and the field; optimum use of the various building trades; sequencing of construction operations for maximum productivity; convenient worker access to construction operations; dealing with inclement weather; making building components fit together; and quality assurance in construction materials and components, through grading, testing, and inspection.

To the novice, these matters may seem of minor consequence when compared to the larger and often more interesting themes of building form and function. To the experienced building professional, who has seen buildings fail both aesthetically and physically for want of attention to one or more of these concerns, they are issues that must be resolved as a matter of course before the work of a building project can be allowed to proceed.

SELECTED REFERENCES

1. Allen, Edward. *How Buildings Work* (2nd ed.). New York, Oxford University Press, 1995.

What do buildings do, and how do they do it? This book sets forth in easily understandable terms the physical principles by which buildings stand up, enclose a piece of the world, and modify it for human use.

2. American Society for Testing and Materials. *ASTM Standards in Building Codes*. Philadelphia, ASTM, updated frequently.

In this volume are found the ASTM standards for all the materials used in the construction of buildings. (Address for ordering: 1916 Race Street, Philadelphia, PA 19103; www.astm.org.)

3. The Construction Specifications Institute and Construction Specifications Canada. *MasterFormat™—Master List of Section Titles and Numbers*. Alexandria, VA, and Toronto, CSI/CSC, updated frequently.

This book gives the full set of numbers and titles under which construction information is filed and utilized. (Address for ordering: 601 Madison Street, Alexandria, VA 22314; www.csinet.org. One St. Clair Avenue West, Suite 1206, Toronto, Ontario M4V 1K6, Canada; www.csc.dcc.ca)

4. International Code Council, Inc. *International Building Code®*. Falls Church, VA, International Code Council, updated frequently.

This is the model building code that is likely to become the standard for most state and local building codes in the United States. (Address for ordering: ICC, Inc., 5203 Leesburg Pike, Suite 600, Falls Church, VA 22041; www.intlcode.org.)

5. Associate Committee on the National Building Code, National Research Council of Canada. *National Building Code of Canada*. (Address for ordering: NRCC, Ottawa, Ontario K1A 0R6, Canada; www.nrc.ca.)

6. Allen, Edward, and Joseph Iano. *The Architect's Studio Companion* (3rd ed.). New York, John Wiley & Sons, Inc., 2001.

This reference book contains precalculated tables that allow an instant determination of the allowable heights and areas for any building under the IBC or Canadian building codes. It also explains clearly what each construction type means, relating it to actual construction materials and structural systems, and it gives extensive rules of thumb for structural systems, mechanical systems, and egress planning.

7. Guise, David. *Design and Technology in Architecture*. New York, John Wiley & Sons, Inc., 1985.

Sixteen illustrated case studies of actual buildings are the core around which this book is built. It deals in a very practical way with the influence of codes, zoning, materials, structure, and mechanical systems on building design.

SOME WEB SITES RELATING TO SUSTAINABILITY

Center of Excellence for Sustainable Development www.sustainable.doe.gov

United States Green Building Council www.usgbc.org

Center for Renewable Energy and Sustainable Technology www.solstice.crest.org

U.S. Environmental Protection Agency www.epa.gov

Environmental Building News www.buildinggreen.com

Green Building Resources Center www.geonetwork.org

American Planning Association Smart Growth www.planning.org/plnginfo/growsmar/gsindex

OTHER WEB SITES

Latest news and product information www.construction.com

John Wiley & Sons, Inc. www.wiley.com

KEY TERMS AND CONCEPTS

zoning ordinance

building code

model building code

National Building Code of Canada

International Building Code (IBC)

Uniform Building Code (UBC)

BOCA National Building Code (BOCA)

Standard Building Code (SBC)

occupancy group

construction type

fire resistance rating

bearing wall

nonbearing wall or partition

access standards

Americans with Disabilities Act (ADA)

Occupational Safety and Health Act

(OSHA)

American Society for Testing and Materials (ASTM)

Canadian Standards Association (CSA)

American National Standards Institute (ANSI)

Construction Specifications Institute (CSI)

MasterFormat

Construction Specifications Canada (CSC)

trade association

sustainability

"green" building

REVIEW QUESTIONS

1. Who are the members of the typical team that designs a major building? What are their respective roles?

2. What are the major constraints under which the designers of a building must work?

3. What types of subjects are covered by zoning ordinances? By building codes?

4. In what units is fire resistance measured? How is the fire resistance of a building assembly determined?

5. If you are designing a five-story office building (Occupancy Group B) with

35,000 square feet per floor, what types of construction will you be permitted to use under the International Building Code if you do not install sprinklers? How does the situation change if you install sprinklers?

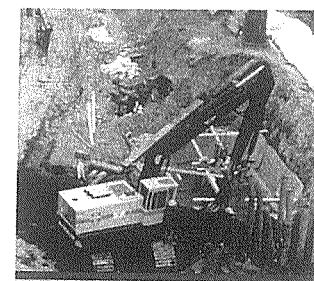
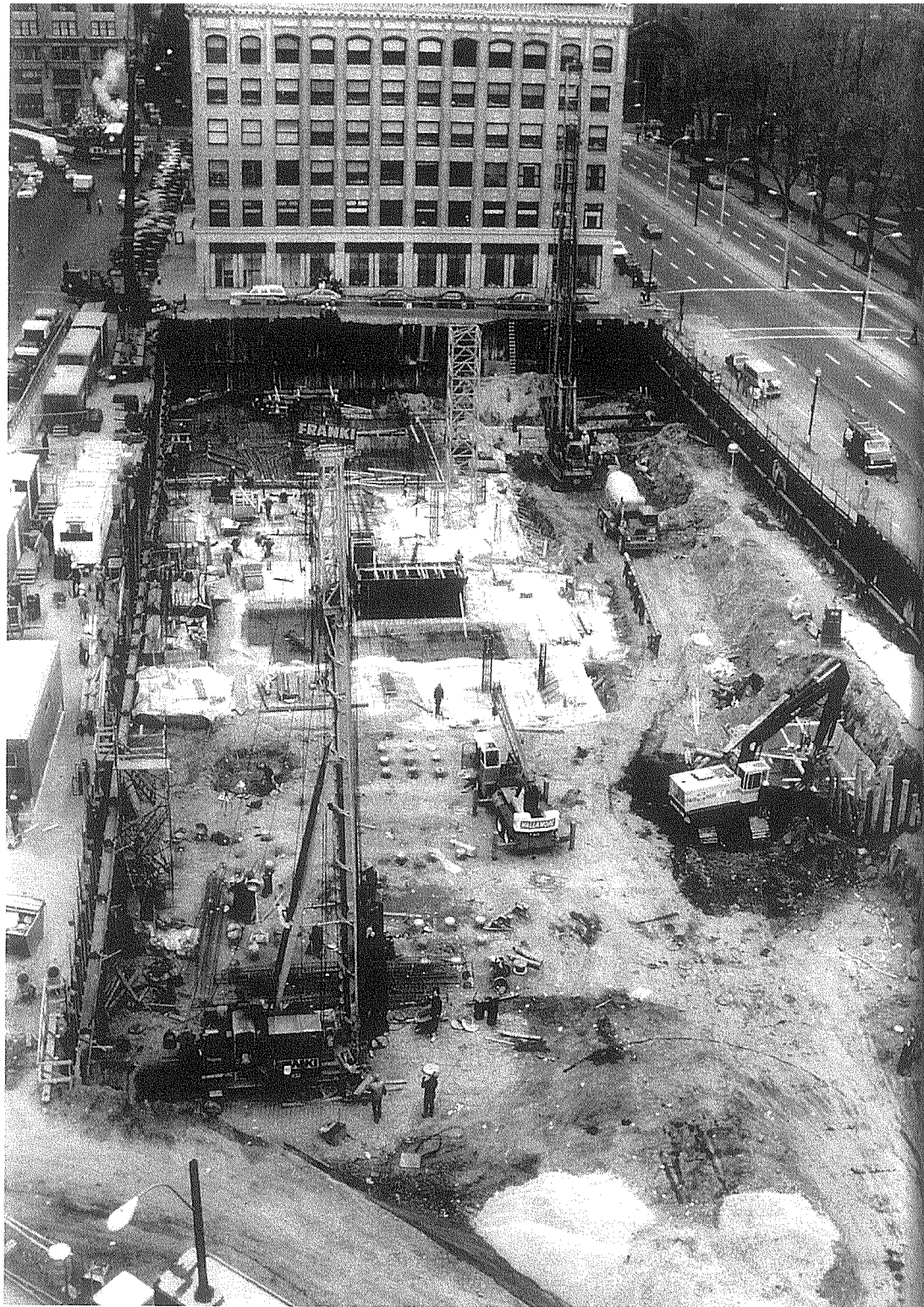
EXERCISES

1. Have each class member write to two or three trade associations at the beginning of the term to request their lists of publications, and then have each send for some of the publications. Display and discuss the publications.

2. Repeat the above exercise for manufacturers' catalogs of building materials and components.

3. Obtain copies of your local zoning ordinance and building code (they may be in your library). Look up the applicable provisions of these documents for a specific site and building. What setbacks are required? How large a building is per-

mitted? What construction types may be employed? What types of roofing materials are permitted? What are the restrictions on interior finish materials? Outline in complete detail the requirements for emergency egress from the building.



FOUNDATIONS

- Foundation Loads
- Foundation Settlement
- Soils
 - Types of Soils
 - Subsurface Exploration and Soil Testing
- Excavation
 - Slope Support
 - Dewatering
- Foundations
 - Shallow Foundations
 - Deep Foundations
- Seismic Base Isolation
- Underpinning
- Retaining Walls
- Waterproofing and Drainage
- Basement Insulation
- Shallow Frost-Protected Foundations
- Backfilling
- Up-Down Construction
- Designing Foundations
- Foundation Design and the Building Codes

Foundation work in progress for a midrise hotel and apartment building in Boston. The earth surrounding the excavation is retained with steel sheet piling supported by steel walers and tiebacks. Equipment enters and leaves the site via the earth ramp at the bottom of the picture. Although a large backhoe at the right continues to dig around old piles from a previous building on the site, the installation of pressure-injected concrete pile footings is already well underway, with two piledrivers at work in the near and far corners, and clusters of completed piles visible in the center of the picture. Concrete pile caps and column reinforcing are under construction in the center of the excavation. (Courtesy of Franki Foundation Company)

The function of a *foundation* is to transfer the structural loads from a building safely into the ground. Every building needs a foundation of some kind: A backyard toolshed will not be damaged by slight movements of its foundations and may need only wooden skids to spread its load across an area of the surface of the ground sufficient to support its weight. A house needs greater stability than a toolshed, so its foundation reaches through the unstable surface to underlying soil that is free of organic matter and unreachable by winter's frost. A larger building of masonry, steel, or concrete weighs many times more than a house, and its foundations probe into the earth until they reach soil or rock that is competent to carry its massive loads; on some sites, this means going a hundred feet or more below the surface. Because of the variety of soil, rock, and water conditions that are encountered below the surface of the ground and the unique demands that many buildings make upon their foundations, foundation design is a highly specialized field of geotechnical engineering, a branch of civil engineering, that can be sketched here only in its broad outlines.

FOUNDATION LOADS

A foundation supports a number of different kinds of loads:

- The *dead load* of the building, which is the sum of the weights of the frame; the floors, roofs, and walls; the electrical and mechanical equipment; and the foundation itself
- The *live load*, which is the sum of the weights of the people in the building; the furnishings and equipment they use; and snow, ice, and water on the roof
- *Wind loads*, which can apply lateral, downward, and uplift loads to a foundation
- Horizontal pressures of earth and water against basement walls

- In some buildings, horizontal *thrusts* from arches, rigid frames, domes, vaults, or tensile structures
- On some building sites, buoyant uplift forces from underground water, identical to the forces that cause a boat to float
- During earthquakes, horizontal and vertical forces caused by the motion of the ground relative to the building

A satisfactory foundation for a building must meet three general requirements:

1. The foundation, including the underlying soil and rock, must be safe against a structural failure that could result in collapse.

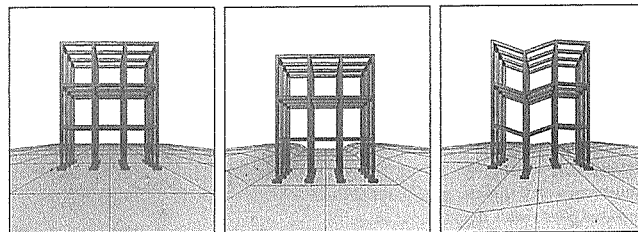
2. During the life of the building, the foundation must not settle in such a way as to damage the structure or impair its function.

3. The foundation must be feasible both technically and economically and practical to build without adverse effects to surrounding property.

FOUNDATION SETTLEMENT

All foundations settle to some extent as the soil around and beneath them adjusts itself to the loads of the building. Foundations on bedrock settle a negligible amount. Foundations on certain types of clay, such as that found in Mexico City, may settle to an alarming degree, allowing buildings to subside by amounts that are measured in feet or meters.

Foundation settlement in most buildings is measured in millimeters or fractions of an inch. If settlement occurs at roughly the same rate from one side of the building to the other, it is called *uniform settlement*, and no harm is likely to be done to the building. If large amounts of *differential settlement* occur, in which the various columns and loadbearing walls of the building settle by substantially different amounts, the frame of the building may become distorted, floors may slope, walls and glass may crack, and doors and windows may refuse to work properly (Figure 2.1). Accordingly, a primary objective in foundation design is to minimize differential settlement by loading the soil in such a way that equal settlement occurs



(a) Building before settlement occurs (b) Uniform settlement (c) Differential settlement

FIGURE 2.1
Uniform settlement (b) is usually of little consequence in a building, but differential settlement (c) can cause severe structural damage.

under the various parts of the building. This is not difficult when all parts of the building rest on the same kind of soil, but can become a problem when a building occupies a site with two or more areas of different types of soil with very different loadbearing capacities. Most foundation failures are attributable to excessive differential settlement. Gross failure of a foundation, in which the soil fails completely to support the building, is extremely rare.

SOILS

Types of Soils

The following distinctions may be helpful in acquiring an initial understanding of how soils are classified for engineering purposes:

- *Rock* is a continuous mass of solid mineral material, such as granite or limestone, that can only be removed by drilling and blasting. Rock is never completely monolithic, but is crossed by a system of joints that divide it into irregular blocks. Despite these joints, rock is generally the strongest and most stable material on which a building can be founded.
- *Soil* is a general term referring to earth material that is particulate.
- If an individual particle of soil is too large to lift by hand, or requires two hands to lift, it is known as a *boulder*.
- If it takes the whole hand to lift a particle, it is a *cobble*.
- If a particle can be lifted easily with thumb and forefinger, the soil is *gravel*. In the Unified Soil Classification System (Figure 2.2), gravels are classified visually as having more than half their particles larger than 0.25 inch (6.5 mm) in diameter.
- If the individual particles can be seen but are too small to be picked up individually, the soil is *sand*. Sand particles range in size from about 0.25 to 0.002 inch (6.5–0.06 mm). Sand and

		Group Symbols	Typical Names
Coarse-Grained Soils	Gravels	GW	Well-graded gravels, gravel-sand mixtures, little or no fines
		GP	Poorly graded gravels, gravel-sand mixtures, little or no fines
	Gravels with Fines	GM	Silty gravels, poorly graded gravel-sand-silt mixtures
		GC	Clayey gravels, poorly graded gravel-sand-clay mixtures
	Sands	SW	Well-graded sands, gravelly sands, little or no fines
		SP	Poorly graded sands, gravelly sands, little or no fines
Fine-Grained Soils	Sands with Fines	SM	Silty sands, poorly graded sand-silt mixtures
		SC	Clayey sands, poorly graded sand-clay mixtures
	Silts and Clays	ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands with plasticity
		CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays
		OL	Organic silts and organic silt-clays of low plasticity
	Highly Organic Soils	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts
		CH	Inorganic clays of high plasticity, fat clays
		OH	Organic clays of medium to high plasticity
		Pt	Peat and other highly organic soils

FIGURE 2.2

A soil classification chart based on the Unified Soil Classification System. The group symbols are a universal set of abbreviations for soil types, as used in Figure 2.7.

gravel are considered to be *coarse-grained soils*.

- *Silt* particles are approximately equidimensional and range in size from 0.002 to 0.00008 inch (0.06–0.002 mm). Because of their low surface-area-to-volume ratio, which approximates that of sand and gravel, the behavior of silt is controlled by the same mass forces that control the behavior of the coarse-grained soils.

- *Clay* particles are plate shaped rather than equidimensional (Figure 2.3) and smaller than silt particles, less than 0.00008 inch (0.002 mm). Clay particles, because of their smaller size and flatter shape, have a surface-area-to-volume ratio hundreds or thousands of times greater than that of silt. As particle size

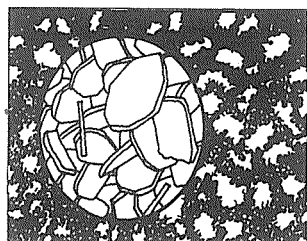
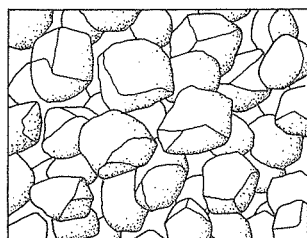


FIGURE 2.3

Silt particles (top) are approximately equidimensional granules, while clay particles (bottom) are platelike and generally much smaller than silt. Notice that the clay particles here are much smaller than the silt particles; a circular area of clay particles has been magnified to make their structure easier to see.

decreases, the size of the pores between the particles also decreases, and soil behavior increasingly depends on surface forces. As particle shape becomes more platelike, the *fabric* (arrangement of particles and pores) becomes more important. The volume of the pores and the amount of water in the pores greatly influence the properties of a clay soil.

- Peat, topsoil, and other organic soils are not suitable for the support of building foundations. Because of their high content of organic matter, they are spongy and compress easily, and their properties can change over time due to changing water content or biological activity in the soil.

Clay soils are generally referred to as being *cohesive*, which means that they retain a measurable shear resistance in the absence of confining forces. To put this more directly, a clay soil sticks together. It is often possible to dig vertical-walled excavations in clay soils (Figure 2.4). In contrast, the ability of a *cohesionless or frictional* soil such as sand or silt to support a building depends on the friction between its particles.

Imagine that you are holding a handful of spherical glass marbles: If you squeeze the marbles, they move readily past one another in your hand. There is little friction between them. However, if you squeeze a handful of crushed stone, whose particles have rough, angular facets, the frictional forces between particles are very large, and there will be little movement between them. The shear resistance of the crushed stone is directly proportional to the confining force pushing the particles together. In the absence of a confining force, the shear resistance disappears and the soil cannot stand with a vertical face. Thus, sand confined by surrounding soil within the earth can support a heavy building, whereas a conical pile of sand on the surface of the earth can support nothing, because there is little or no shear resistance between the particles.

Beneath every building site lies a number of superimposed layers (*strata*) of different soils. These strata were deposited one after another in very ancient times by volcanic action and by the action of water, wind, and ice. Most of the soils in these strata are mixtures of several different sizes and types of particles and bear such names as silty gravels, gravelly sands, clayey sands, silty clays, and so on (Figure 2.2). The relative proportions of particle sizes and types in a soil are important to know when designing a foundation because they are helpful in predicting the load-bearing capacity of the soil, its stability, and its drainage characteristics.

Figure 2.5 gives some conservative values of loadbearing capacities for various types of soils. These values give only a general idea of the relative strengths of different soils; the strength of an actual soil is also dependent on factors such as the presence or absence of water, the depth at which the soil lies beneath the surface, and the size of the foundation that applies the load to the soil. The designer may also arbitrarily choose to reduce the pressure of the foundations on the soil to well below these values in order to reduce the anticipated amount of settlement of the building. Rock is generally the

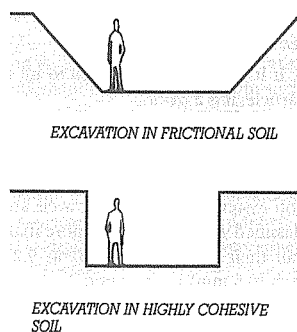


FIGURE 2.4
Excavations in highly cohesive and frictional soils.

best material on which to found a building; the proliferation of tall office buildings in Manhattan is attributable in part to the bedrock that lies a short distance beneath the surface. When rock is too deep to be reached by foundations, the designer must choose from the strata of different soils that lie closer to the surface and design a foundation to perform satisfactorily in the selected soil.

The *stability* of a soil is its ability to retain its engineering properties under the varying conditions that may occur during the lifetime of the building. Rock, gravels, sands, and many silts tend to be stable soils. Many clays are dimensionally unstable under changing subsurface moisture conditions. Clay may swell considerably as it absorbs water and shrink as it dries. When wet clay is put under pressure, water can be squeezed out of it, with a corresponding reduction in volume. Taken together, these properties make clays that are subject to changes in water content the least stable and least predictable soils for supporting buildings.

The drainage characteristics of a soil are important in predicting how water will flow on and under building sites and around building structures. Water passes readily through the extensive voids in clean gravels and coarse sands, slowly through very fine silts and sands, and almost not at all through many clays. A building site with clayey or silty soils near the surface drain poorly and is likely to be muddy and covered with puddles during rainy periods, whereas a gravelly site is likely to remain virtually dry. Underground, water passes quickly through strata of gravel and sand, but accumulates above strata of clay and fine silt. An excellent way to keep a basement dry is to surround it with a thick layer of clean gravel or crushed stone. Water passing through the soil toward the building cannot reach the basement without first falling to the bottom of the gravel layer, from where it can be drawn off in perforated pipes before it accumulates (Figures 2.55 and 2.56). It does little good to place perforated drainage pipes directly in clay

or silt because water cannot flow through the impervious soil toward the pipes.

Subsurface Exploration and Soil Testing

Prior to designing a foundation for any building larger than a single-family house, it is necessary to determine the soil and water conditions beneath the site. This can be done by digging *test pits* or by making *test borings*. Test pits are useful when the foundation is not expected to extend deeper than about 8 feet (2.5 m), which is the maximum practical reach of small excavating machines. The strata of the soil can be observed and measured in the pit, and soil samples can be taken for laboratory testing. The level of the *water table* (the elevation at which the pressure of the groundwater is atmospheric) will be readily apparent in coarse-grained soils if it falls within the depth of the pit because water will seep through the walls of the pit up to the level of the water table. On the other hand, if

TABLE 1804.2
ALLOWABLE FOUNDATION AND LATERAL PRESSURE

CLASS OF MATERIALS	ALLOWABLE FOUNDATION PRESSURE (psf) ^a	LATERAL BEARING (psf/ft below natural grade) ^b	LATERAL SLIDING	
			Coefficient of friction ^c	Resistance (psf) ^d
1. Crystalline bedrock	12,000	1,200	0.70	—
2. Sedimentary and foliated rock	4,000	400	0.35	—
3. Sandy gravel and/or gravel (GW and GP)	3,000	200	0.35	—
4. Sand, silty sand, clayey sand, silty gravel and clayey gravel (SW, SP, SM, SC, GM and GC)	2,000	150	0.25	—
5. Clay, sandy clay, silty clay, clayey silt, silt and sandy silt (CL, ML, MH and CH)	1,500 ^e	100	—	130

For SI: 1 pound per square foot = 0.0479 kPa, 1 pound per square foot per foot = 0.157 kPa/m.

a. Coefficient to be multiplied by the dead load.

b. Lateral sliding resistance value to be multiplied by the contact area, as limited by Section 1804.3.

c. Where the building official determines that in-place soils with an allowable bearing capacity of less than 1,500 psf are likely to be present at the site, the allowable bearing capacity shall be determined by a soils investigation.

d. An increase of one-third is permitted when considering load combinations, including wind or earthquake loads, as permitted by Section 1605.3.2.

FIGURE 2.5

Presumptive surface bearing values of various soils, as given in the 2000 International Building Code. Classes 3, 4, and 5 are keyed to the group symbols in Figure 2.2.

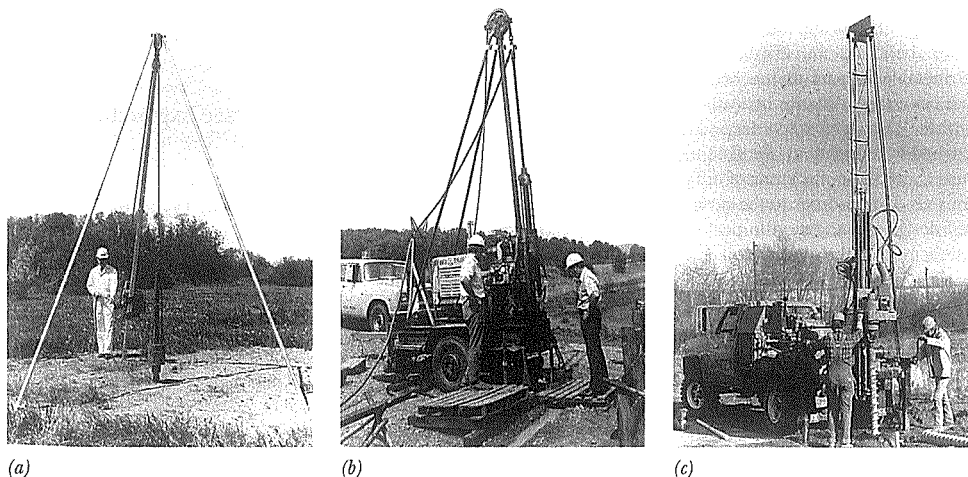


FIGURE 2.6

Examples of soil test boring equipment. (a) A portable cathead drilling rig. A small gasoline engine on the leg of the tripod next to the operator spins a metal drum called a "cathead." By alternately tightening and loosening the loops of rope around the cathead, the operator lifts and drops the cylindrical weight to drive a casing or a sampling tube into the earth. (b) A trailer-mounted hydraulic feed core drill. (c) A truck-mounted hydraulic drill rig with core augers. (Courtesy of Acher Drill Company, Inc.)

a test pit is excavated below the water table in clay, free water will not seep into the pit because the clay is relatively impermeable. In this case, the level of the water table must be determined by means of an observation well or special electronic devices that are installed to measure water pressure. If desired, a load test can be performed on the soil in the bottom of a test pit to determine the stress the soil can safely carry and the amount of settlement that should be anticipated under load.

If a pit is not dug, borings with standard penetration tests can give an indication of the bearing capacity of the soil by the number of blows of a standard driving hammer required to advance a sampling tube into the soil by a fixed amount. Test boring (Figure 2.6) extends the possible range of exploration much deeper into the earth than test pits and returns information on the thickness and locations of the soil strata and the depth of the water table. Laboratory-quality

soil samples can also be recovered for testing. Usually, a number of holes are drilled across the site; the information from the holes is coordinated and interpolated in the preparation of drawings that document the subsurface conditions for the use of the engineer who will design the foundation (Figure 2.7).

Laboratory testing of soil samples is an important preliminary to foundation design. By passing a dried sample of coarse-grained soil through a set of sieves with graduated mesh sizes, the particle size distribution in the soil can be determined. Further tests on fine-grained soils assist in their identification and provide information on their engineering properties. Important among these are tests that establish the *liquid limit*, the water content at which the soil passes from a plastic state to a liquid state, and the *plastic limit*, the water content at which the soil loses its plasticity and begins to behave as a solid. Additional tests can

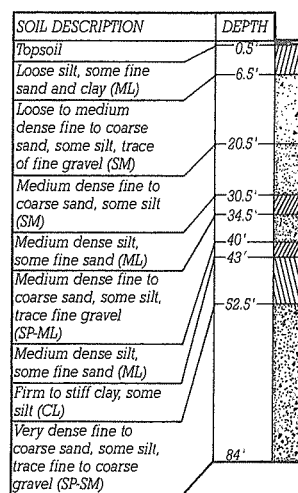


FIGURE 2.7

A typical log from a soil test boring, indicating the type of soil in each stratum and the depth in feet at which it was found. The abbreviations in parentheses refer to the Unified Soil Classification System, and are explained in Figure 2.2.

determine the water content of the soil, its permeability to water, its shrinkage when dried, its shear and compressive strengths, the amount by which the soil can be expected to consolidate under the load, and the rate at which the consolidation will take place (Figure 2.8). These latter two qualities are helpful in predict-

ing the rate and magnitude of foundation settlement in a building.

The information gained through subsurface exploration and soil testing is summarized in a written soils report. This report includes the results of both the field tests and the laboratory tests, recommended types of foundations for the site, recom-

mended depths and bearing stresses for the foundations, and an estimate of the expected rate of foundation settlement. This information can be used directly by foundation and structural engineers in the design of the excavations, dewatering and slope support systems, foundations, and substructure.

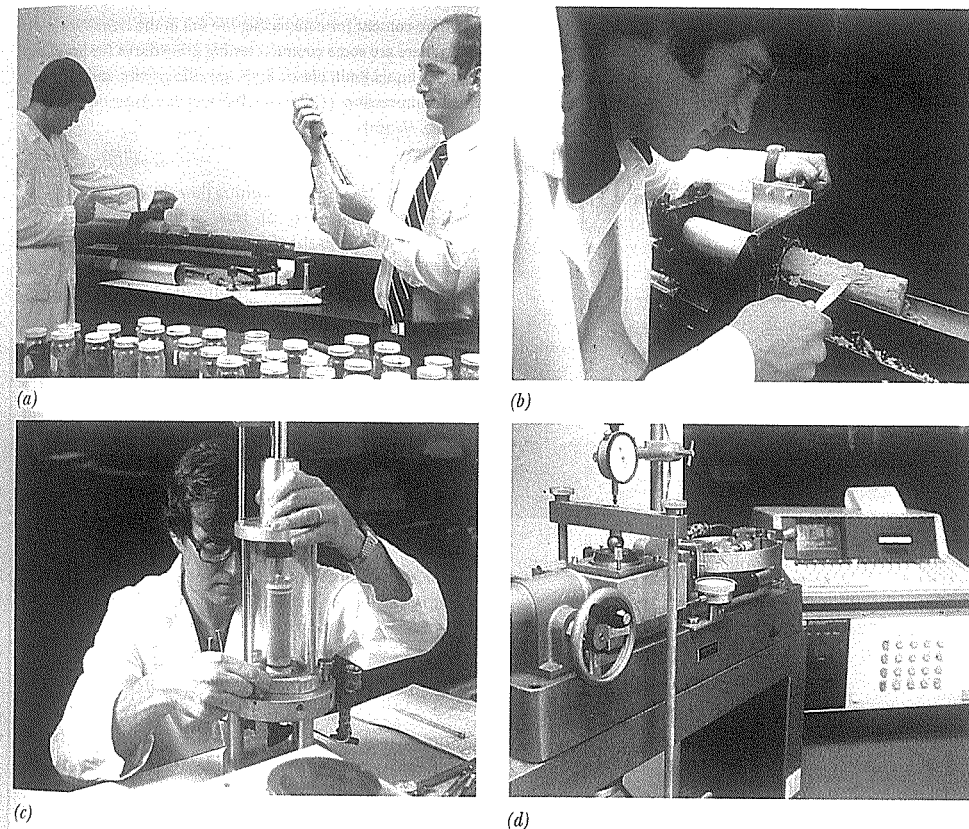


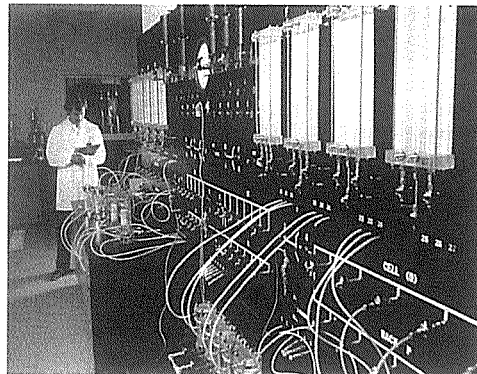
FIGURE 2.8

Some laboratory soil testing procedures. (a) To the right, the hardness of split spoon samples is checked with a *penetrometer* to be sure that they come from the same stratum of soil. To the left, a soil sample from a Shelby sampling tube is cut into sections for testing. (b) A section of undisturbed soil from a Shelby tube is trimmed to examine the stratification of silt and clay layers. (c) A cylindrical sample of soil is set up for a triaxial load test, the principal method for determining the shear strength of soil. The sample will be loaded axially by the piston in the top of the apparatus, and also circumferentially by water pressure in the transparent cylinder. (d) A direct shear test, used to measure the shear strength of cohesionless soils. A rectangular prism of soil is placed in a split box and sheared by applying pressure in opposite directions to the two halves of the box.

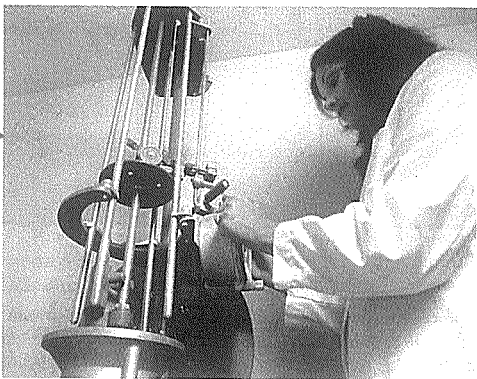
(continued)



(e)



(f)



(g)

FIGURE 2.8 (continued)

(e) One-dimensional consolidation tests in progress on fine-grained soils, to determine their compressibility and expected rate of settlement. Each sample is compressed over an extended period of time to allow water to flow out of the sample. (f) A panel for running 30 simultaneous constant-head permeability tests, to determine the rate at which a fluid, usually water, moves through a soil. (g) A Proctor compaction test, in which successive layers of soil are compacted with a specified tamping force. The test is repeated for the same soil with varying moisture content, and a curve is plotted of density achieved versus moisture content of the soil, to identify an optimum moisture content for compacting the soil in the field. Not shown here are some common testing procedures for grain size analysis, liquid limit, plastic limit, specific gravity, and unconfined compression. (Courtesy of Ardamian and Associates, Inc., Orlando, Florida)

SOME CONSIDERATIONS OF SUSTAINABILITY IN SITE WORK, EXCAVATIONS, AND FOUNDATIONS

Site Selection

- Buying and renovating an existing building rather than building a new one saves a great deal of building material. If the existing building has been scheduled for demolition, it also avoids dumping an enormous quantity of material into a landfill.
- Building on a damaged site, and designing the building so that it helps to restore it, benefits the environment rather than degrading it.
- Building on agricultural land takes that land out of production forever.
- Building in forests and on wetlands and prairies destroys wildlife habitat.
- A building that is well connected to existing networks of public transportation, and to pedestrian and bicycle paths, pays environmental dividends every day for the life of the building by saving fuel, reducing air pollution from automobiles, and minimizing commute times.

Site Design

- Large existing trees cannot be replaced except by growing new ones, which takes many decades. Planting of new trees is always a good thing, but preservation of existing trees is even better.
- Protection and enhancement of the health of ecosystems such as marshes, lakes, forests, and prairies is essential to the maintenance of biodiversity.
- Distinctive site features such as rock formations, forests, grasslands, streams, marshes, and recreational paths and facilities, if destroyed by construction, can never be replaced.
- Grading the site to appropriate slopes and planting vegetation that holds the soil in place will prevent erosion.
- A drainage system that conducts water to areas on the site where it is absorbed into the earth works to replenish natural aquifers and avoids overloading of storm sewers.
- Building above the water table helps to avoid disturbance of aquifers.
- A new building that shades adjacent buildings deprives them of natural illumination and, in many cases, useful solar heat. The result is an increase in the amount of elec-

tricity and heating fuel used by the shaded buildings.

- Siting a building for best exposure to sun and wind maximizes solar heat gain in winter and minimizes it in summer to save heating and air conditioning fuel. It also allows utilization of daylight to replace electric lighting.
- In general, a building should be designed in such a manner that the site does the heaviest work of environmental modification through good orientation to sun and wind, trees that are placed so as to provide shade and windbreaks, and use of below-grade portions of the building for thermal mass. The passive shell of the building can do most of the rest of the work through orientation of windows with respect to sunlight, good thermal insulation and airtightness, utilization of thermal mass, and tight multipane windows. The active heating, cooling, and lighting equipment should serve only to fine-tune the interior environment, using as little fossil fuel and electricity as possible.

Construction Process

- It is essential to protect trees and sensitive areas of the site from damage during construction.
- A building should comply with all local conservation laws relating to soils, wetlands, and stormwater.
- Topsoil should be stockpiled carefully during construction and reused on the site.
- It is important to guard against soil erosion by water and wind during construction.
- Vehicle tires compact soil so that it cannot absorb water or support vegetation. Thus, it is important to develop minimal, well-marked access routes for trucks and construction machinery that minimize soil compaction, as well as minimizing noise, dust, air pollution, and inconvenience to neighboring buildings and sites.
- Construction machinery should be selected and maintained so that it pollutes the air as little as possible.
- Surplus excavated soils should be reused either on the site or on another site nearby.
- Construction wastes should be recycled as much as possible.

EXCAVATION

At least some *excavation* is required for every building. Organic topsoil is subject to decomposition and to shrinking and swelling with changes in moisture content. It is excellent for growing lawns and landscape plants, but too unstable to support a building, so it is scraped away from the building area and stockpiled to one side for redistribution over the site after construction of the building is complete. After the topsoil has been removed, further digging is necessary to place the footings out of reach of water and wind erosion and, in colder climates, to place them below the level to which the ground freezes in winter. Soil expands slightly as it freezes, with a force that can lift and break buildings. Under certain soil and temperature conditions, upward migration of water vapor from the pores in the soil can result in the formation of *ice lenses*, thick layers of frozen water crystals that can lift buildings by even larger amounts, unless the foundations are placed below the frost line or are insulated in such a way that the soil beneath them cannot freeze.

Excavation is required on many sites to place the footings at a depth where soil of the appropriate bearing capacity is available. Excavation is frequently undertaken so that one or more levels of basement space can be added to a building, whether for additional habitable rooms, for parking, or for mechanical equipment and storage. Where footings must be placed deep to get below the frost

line or reach competent soil, a basement is often bargain-rate space, adding little to the overall cost of the building.

In particulate soils, a variety of excavating machines can be used to loosen and lift the soil from the ground: bulldozers, shovel dozers, backhoes, bucket loaders, scrapers, trenching machines, and power shovels of every type. If the soil must be moved more than a short distance, dumptrucks come into use.

In rock, excavation is slower and many times more costly. Weak or decomposing rock can sometimes be fractured and loosened with power shovels, tractor-mounted rippers, pneumatic hammers, or drop balls such as those used in building demolition. Blasting, in which explosives are placed and detonated in lines of closely spaced holes drilled deep into the rock, is often necessary. On tight urban sites where blasting is impractical, rock can be fractured with hydraulic splitters.

Slope Support

If the site is sufficiently larger than the area to be covered by the building, the edges of the excavation can be sloped back or *benched* at an angle such that the soil will not slide back into the hole. This angle can be steep for cohesive soils such as the stiffer clays, but must be shallow for frictional soils such as sand and gravel. On constricted sites, the soil around an excavation must be held back by temporary walls called *sheeting*. The sheeting, in turn, must be supported

If . . . solid ground cannot be found, but the place proves to be nothing but a heap of loose earth to the very bottom, or a marsh, then it must be dug up and cleared out and set with piles made of charred alder or olive wood or oak, and these must be driven down by machinery, very closely together . . .

Marcus Vitruvius Pollio,
first century B.C.

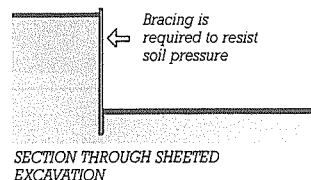
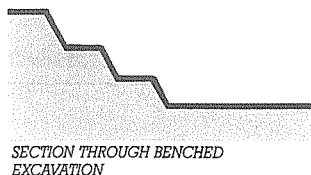
against the pressure of the earth and water it retains (Figure 2.9). If the sheeting is less than one story tall, this can often be done by driving it deeply enough into the soil that it can act as a vertical cantilever beam. For taller walls, and in less stable soils, some form of bracing is required for support.

Sheeting

Sheeting can take any of several forms, depending on the qualities of the soil and circumstances such as the equipment and preferences of the contractor, the proximity of surrounding buildings, the level of the water table, or a desire to retain the sheeting as a permanent part of the substructure of the building. Among the most common forms of sheeting are soldier beams and lagging, sheet

FIGURE 2.9

On a spacious site, an excavation can be benched. On an urban site with nearby buildings, lack of space often requires the use of sheeting to retain the soil around an excavation.



piling, and slurry walls. *Soldier beams* are steel wide-flange sections driven vertically into the earth at close intervals around an excavation site before digging begins. As earth is removed, *lagging*, usually consisting of heavy wood planks, is placed against the flanges of the soldier beams to retain the soil outside the excavation (Figures 2.10 and 2.11). The soldier beams and lagging may be removed after construction of the substructure has been completed.

Sheet piling consists of vertical planks of wood, steel, or precast concrete that are placed tightly against one another and driven into the earth to form a solid wall before excavation begins (Figures 2.12 and 2.13).

Steel and precast concrete sheet piling are often left in place as part of the substructure of the building, or, like wood sheet piling, they may be pulled from the soil when their work is finished.

A *slurry wall* is a more complicated and expensive type of sheeting that is usually economical only if it becomes the permanent foundation wall of the building. The first steps in creating a slurry wall are to lay out the wall location on the surface of the ground with surveying instruments and to define the location and thickness of the wall with shallow poured concrete *guide walls* (Figures 2.14 and 2.15). When the formwork has been removed from the guide walls, a spe-

cial narrow *clamshell bucket*, mounted on a crane, is used to excavate the soil from between the guide walls. As the narrow trench deepens, the tendency of its earth walls to collapse is counteracted by filling the trench with a slurry of bentonite clay and water, which exerts a pressure back against the earth walls, holding them in place. The clamshell bucket is lowered and raised through the slurry to continue excavating the soil from the bottom of the trench until the desired depth has been reached, often a number of stories below the ground. Slurry is added as required to keep the trench full at all times.

Meanwhile, workers have welded together cages of steel bars designed

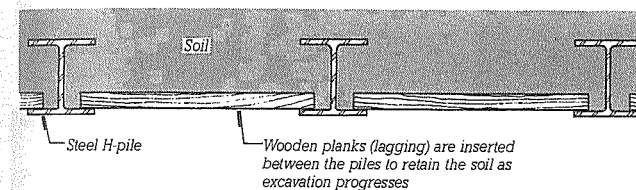


FIGURE 2.10

Soldier beams and lagging, seen in horizontal section.

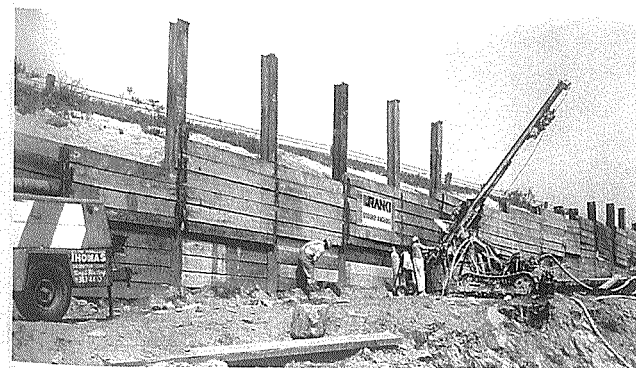


FIGURE 2.11

Soldier beams and lagging. Lagging planks are added at the bottom as excavation proceeds. The drill rig is boring a hole for a tieback to support the soldier beams.

(Courtesy of Franki Foundation Company)

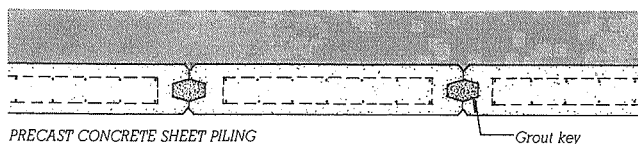
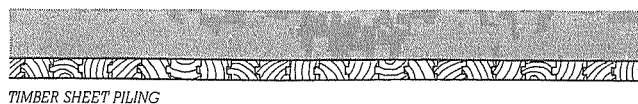


FIGURE 2.12
Horizontal sections through three types of sheet piling. The shading represents the retained earth.

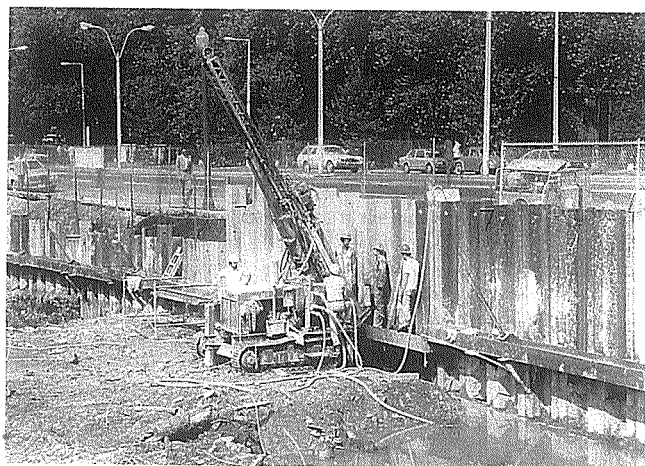


FIGURE 2.13
Drilling tieback holes for a wall of steel sheet piling. Notice the completed tieback connections to the waler in the foreground and background. The hole in the top of each piece of sheet piling allows it to be lifted by a crane. (Courtesy of Franki Foundation Company)

to reinforce the concrete wall that will replace the slurry in the trench. Steel tubes whose diameter corresponds to the width of the trench are driven vertically into the trench at predetermined intervals to divide it into sections of a size that can be reinforced and concreted conveniently. The concreting of each section begins with the lowering of a cage of reinforcing bars into the slurry. Then

concrete is poured into the trench from the bottom up, using a funnel-and-tube arrangement called a *tremie*. As the concrete rises in the trench, it displaces the slurry, which is pumped out into holding tanks, where it is stored for reuse. After the concrete reaches the top of the trench and has hardened sufficiently, the vertical pipes on either side of the recently poured section are withdrawn from

the trench, and the adjoining sections are poured. This process is repeated for each section of the wall. When the concrete in all the trenches has cured to its intended strength, earth removal begins inside the wall, which serves as sheeting for the excavation.

In addition to the *sitecast* concrete slurry wall described in the preceding paragraphs, *precast concrete*

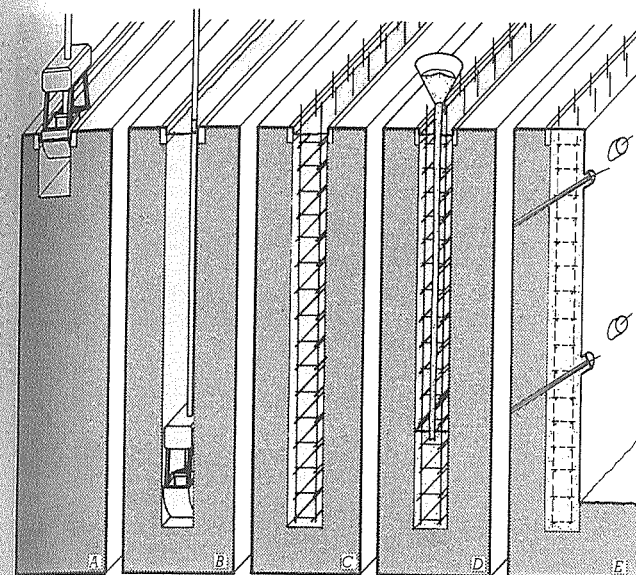
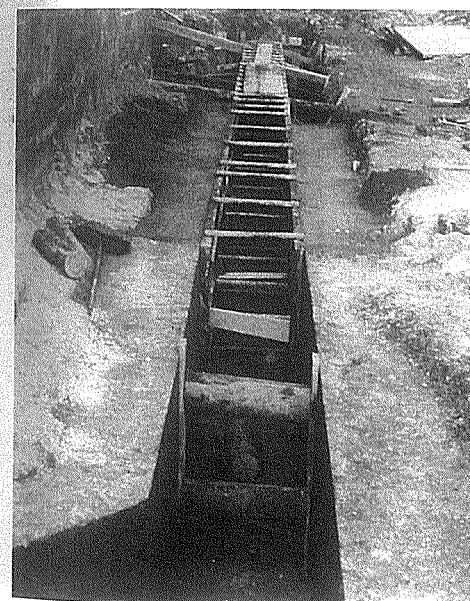
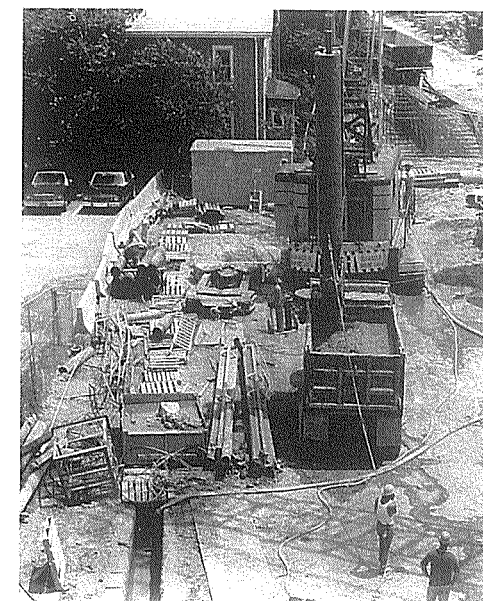


FIGURE 2.14
Steps in constructing a slurry wall. (a) The concrete guide walls have been installed, and the clamshell bucket begins excavating the trench through a bentonite clay slurry. (b) The trench is dug to the desired depth, with the slurry serving to prevent collapse of the walls of the trench. (c) A welded cage of steel reinforcing bars is lowered into the slurry. (d) The trench is concreted from the bottom up with the aid of a tremie. The displaced slurry is pumped from the trench, filtered, and stored for reuse. (e) The reinforced concrete wall is tied back as excavation progresses.



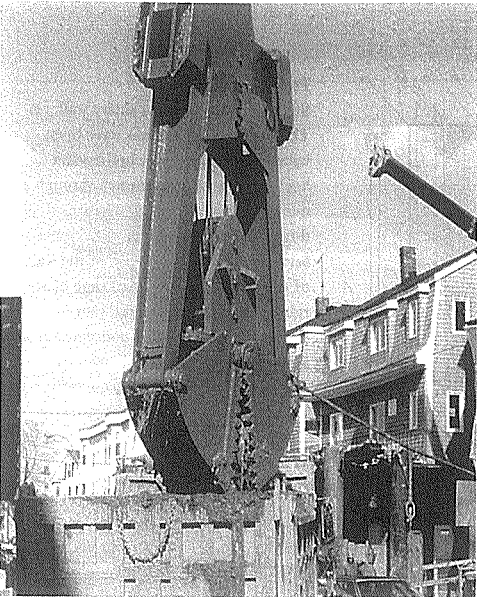
(a)



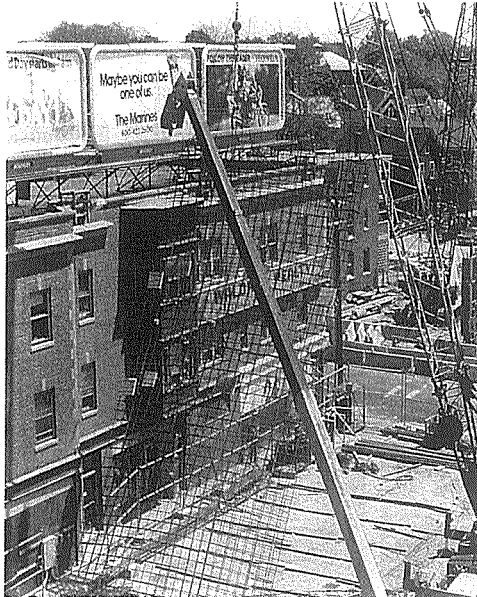
(b)

FIGURE 2.15
Constructing a slurry wall. (a) The guide walls are formed and poured in a shallow trench. (b) The narrow clamshell bucket discharges a load of soil into a waiting dump truck. Most of the trench is covered with wood pallets for safety.

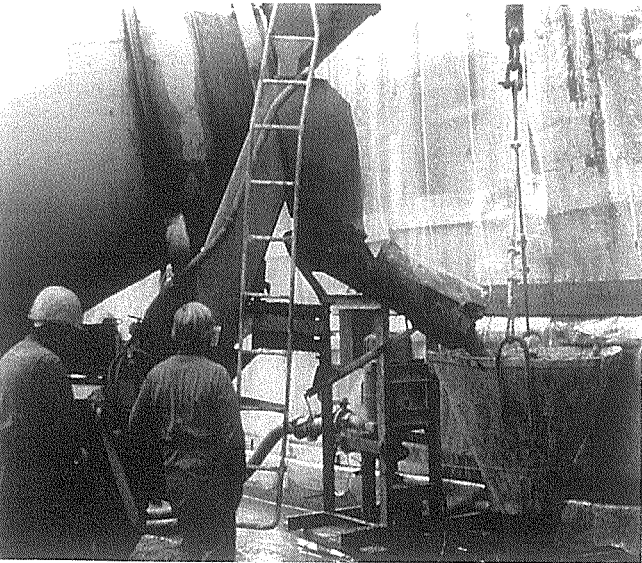
(continued)



(c)



(d)



(e)

slurry walls are also built. The slurry for precast walls is a mixture of water, bentonite clay, and portland cement. The wall is prestressed and is pro-

duced in sections in a precasting plant (see Chapter 15), then trucked to the construction site. Before a section is lowered by a crane into the

FIGURE 2.15 (continued)
(c) A detail of the narrow clamshell bucket used for slurry wall excavation.
(d) Hoisting a reinforcing cage from the area where it was assembled, getting ready to lower it into the trench. The depth of the trench and height of the slurry wall are equal to the height of the cage, which is about four stories for this project.
(e) Concreting the slurry wall with a tremie. The pump just to the left of the tremie removes slurry from the trench as concrete is added. (Photos b, c, and d courtesy of Franki Foundation Company. Photos a and e courtesy of Soletanche)

slurry, its face is coated with a compound that prevents the clay-cement slurry from adhering to it (Figure 2.16). The sections are installed side

by side in the trench, joined by tongue-and-groove edges or synthetic rubber gaskets. After the portland cement has caused the slurry to harden to a soil-like consistency, excavation can begin, with the hardened slurry on the inside face of the wall dropping away from the coated surface as soil is removed. The primary advantages of a precast slurry wall over a sitecast one are better surface quality, more accurate wall alignment, a thinner wall (due to the structural efficiency of prestressing), and improved watertightness of the wall because of the continuous layer of solidified clay outside.

Soil Mixing

Soil mixing is a technique of adding a modifying substance to soil and blending it in place by means of paddles rotating on the end of a vertical shaft (Figure 2.17). This technique has several different applications, one of which is to remediate soil contaminated with a chemical or biologi-

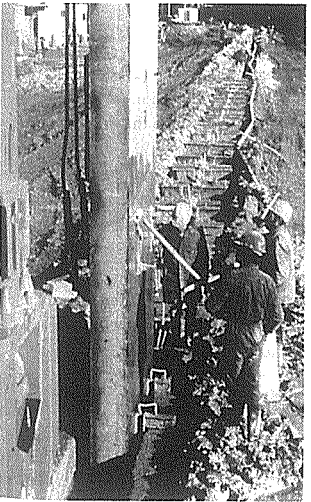


FIGURE 2.16
Workers apply a nonstick coating to a section of precast concrete slurry wall as it is lowered into the trench.
(Courtesy of Soletanche)

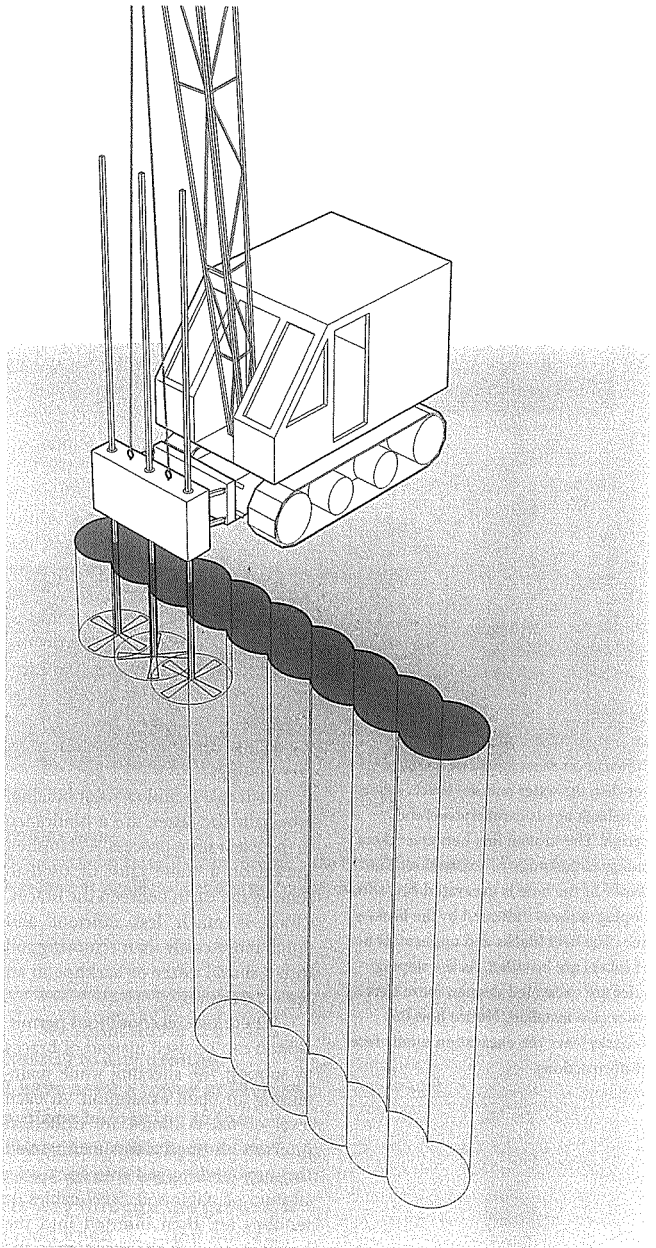


FIGURE 2.17
Soil mixing.

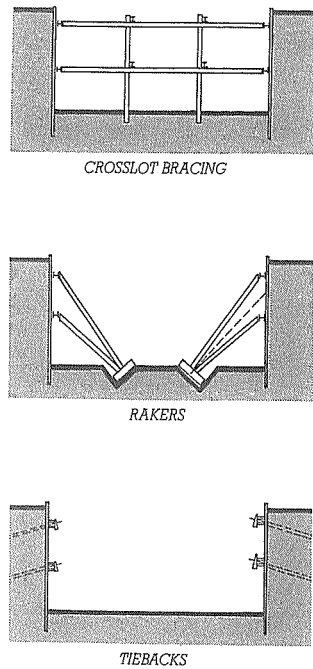


FIGURE 2.18

Three methods of bracing sheeting, drawn in cross section. The connection between the waler and the brace, raker, or tieback needs careful structural design. The broken line between rakers indicates the mode of excavation: The center of the hole is excavated first with sloping sides as indicated by the broken line. The heel blocks and uppermost tier of rakers are installed. As the sloping sides are excavated deeper, more tiers of rakers are installed. Notice how the tiebacks leave the excavation totally free of obstructions.

cal substance by blending it with a chemical that renders it harmless. Another is to mix portland cement and water with a soil to create a cylinder of low-strength concrete in the ground. A linear series of these cylinders can serve as a cutoff wall against water penetration and, in some cases, as sheeting for an excavation. Soil mixing can also serve to stabilize and strengthen areas of weak soil.

Bracing

Soldier beams, sheet piling, and slurry walls all need to be braced against soil and water pressures as the excavation deepens (Figure 2.18). *Crosslot bracing* utilizes temporary steel wide-flange columns that are driven into the earth by a piledriver at points where braces will cross. As the earth is excavated down around the sheeting and the columns, tiers of horizontal bracing struts, usually of steel, are added to support *walers*, which are beams that span across the face of the sheeting. Where the excavation is too wide for crosslot bracing, sloping *rakers* are used instead, bearing against *heel blocks* or other temporary footings.

Both rakers and crosslot bracing, especially the latter, are a hindrance to the excavation process. A clamshell bucket on a crane must be used to remove the earth between the braces, which is much less efficient and much more costly than removing soil with a shovel dozer or backhoe in an open excavation.

Where subsoil conditions permit, *tiebacks* can be used instead of braces to support the sheeting while maintaining an open excavation. At each level of walers, holes are drilled at intervals through the sheeting and the surrounding soil into rock or a stratum of stable soil. Steel cables or tendons are then inserted into the holes, grouted to anchor them to the rock or soil, and stretched tight with hydraulic jacks (posttensioned) before they are fastened to the walers (Figures 2.19 and 2.20).

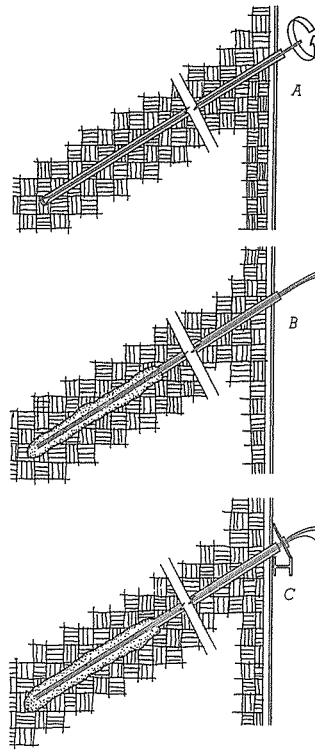


FIGURE 2.19

Three steps in the installation of a tieback to a soil anchor. (a) A rotary drill bores a hole through the sheeting and into stable soil or rock. A steel pipe casing keeps the hole from caving in where it passes through noncohesive soils. (b) Steel prestressing tendons are inserted into the hole and grouted under pressure to anchor them to the soil. (c) After the grout has hardened, the tendons are tensioned with a hydraulic jack and anchored to a waler.



(a)

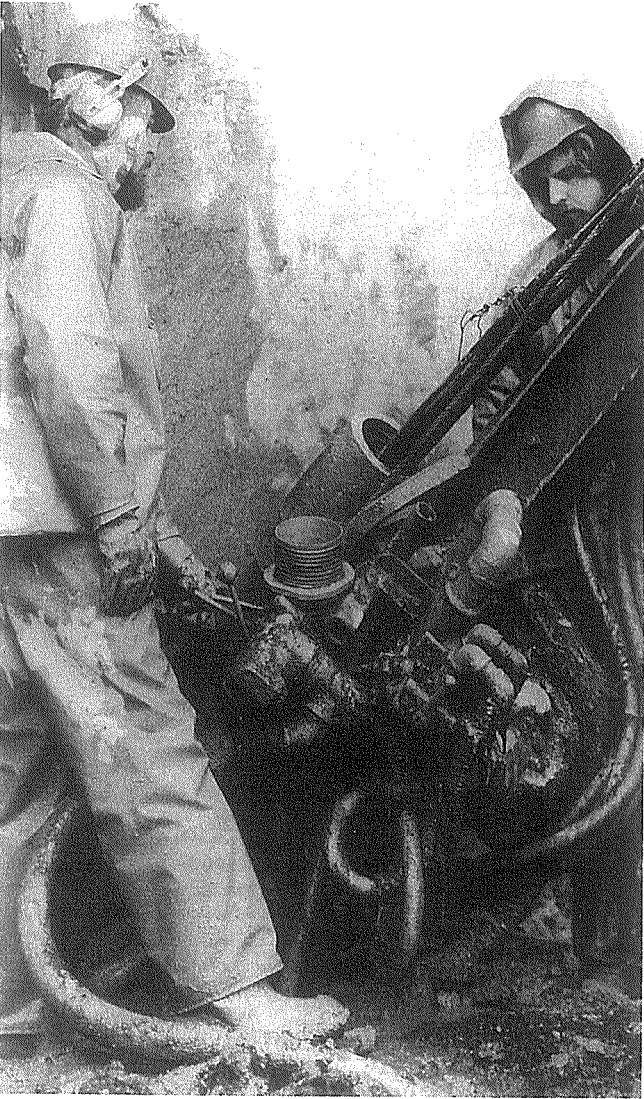
FIGURE 2.20

Installing tiebacks. (a) Drilling through a slurry wall for a tieback. The ends of hundreds of completed tiebacks protrude from the wall.

(continued)

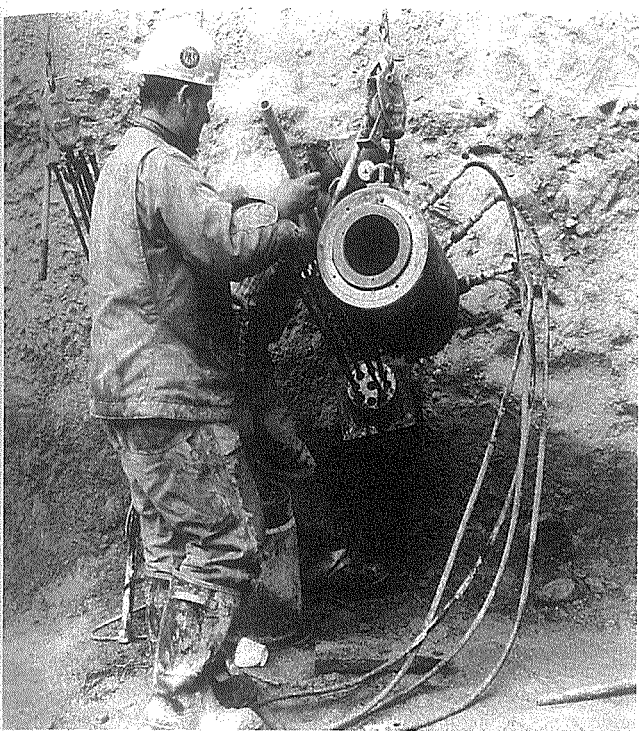
We must never trust too hastily to any ground. . . . I have seen a tower at Mestre, a place belonging to the Venetians, which, in a few years after it was built, made its way through the ground it stood upon . . . and buried itself in earth up to the very battlements.

Leon Battista Alberti, 1404-1472



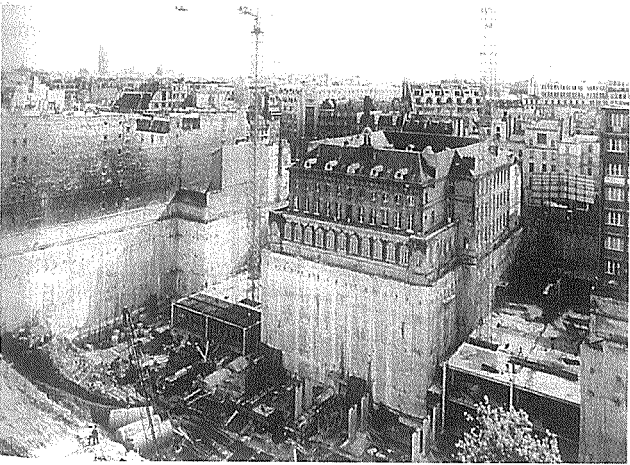
(b)

FIGURE 2.20 (continued)
(b) Inserting prestressing tendons into the steel casing for a tieback. The apparatus in the center of the picture is for pressure injecting grout around the tendons.



(c)

FIGURE 2.20 (continued)
(c) After the tendons have been tensioned, they are anchored to a steel chuck that holds them under stress, and the cylindrical hydraulic jack is moved to the next tieback. (d) Slurry walls and tiebacks used to support historic buildings around deep excavations for a station of the Paris Metro. (Photos, a, b, and c courtesy of Franki Foundation Company. Photo d courtesy of Soletanche)



(d)

Excavations in fractured rock can often avoid sheeting altogether, either by injecting grout into the joints of the rock to stabilize it or by drilling into the rock and inserting *rock anchors* that fasten the blocks together (Figure 2.21).

In some cases, vertical walls of particulate soils can be stabilized by *soil nailing*. A soil nail is similar to a rock anchor: It is a length of steel reinforcing bar that is inserted into a nearly horizontal hole drilled deep into the soil. Grout is injected into the hole to bind the soil nail to the surrounding soil. Large numbers of closely spaced nails are used to knit a large block of soil together so that it behaves more like weak rock than particulate soil.

Bracing and tiebacks in excavations are usually temporary. Their function is taken over permanently by the floor structure of the basement levels of the building, which is designed specifically to resist lateral loads from the surrounding earth as well as ordinary floor loads.

Dewatering

Specifications, building codes, and economy require that foundation construction be performed "in the dry," meaning an excavation that is

free of water. When excavation work is carried out below the water table in the surrounding soil, the site must be *dewatered*. The most common method of dewatering is to pump the water from *sumps*, which are pits in the bottom of the excavation. In certain types of soils, particularly sands and silt, the seepage into the sumps may soften the undisturbed soil on which the foundations bear. In this case, it may be necessary to keep groundwater from entering the excavation, either by pumping water from the surrounding soil to depress the water table below the level of the bottom of the excavation or by erecting a watertight barrier around the excavation (Figure 2.22).

Well points are commonly used to depress the water table. These are vertical pieces of pipe with screened openings at the foot that keep out soil particles while allowing water to enter. Closely spaced well points are driven into the soil around the entire circumference of the excavation. These are connected to horizontal header pipes leading to pumps that continually suck water from the system and discharge it away from the building site. Once pumping has drawn down the water table in the area of the excavation, work can continue "in the dry" (Figure 2.23). For

excavations deeper than the 20 feet (6 m) or so that can be drained by a suction pump stationed at ground level, two rings of well points may be required, the inner ring being driven to a deeper level than the outer ring, or a single ring of deep wells with submersible force pumps may have to be installed.

In some cases, the lowering of the water table by well points or deep wells can have serious adverse effects on neighboring buildings by causing consolidation and settling of soil under their foundations or by exposing untreated wood foundation piles, previously protected by total immersion in water, to decay. In these cases, a *watertight barrier* wall is used as an alternative to well points (Figure 2.22). A slurry wall makes an excellent watertight barrier. Sheet piling can also work, but tends to leak at the joints. A watertight barrier must resist the hydrostatic pressure of the surrounding water, which grows greater as the foundation grows deeper, so a strong system of bracing or tiebacks is required. A watertight barrier only works if it reaches into a stratum of impermeable soil such as clay that lies beneath the water table. Otherwise, water will flow beneath the barrier and up into the excavation.

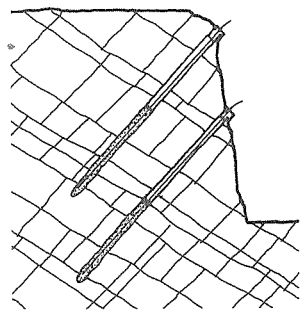


FIGURE 2.21
Rock anchors are similar to tiebacks, but are used to hold jointed rock formations in place around an excavation.

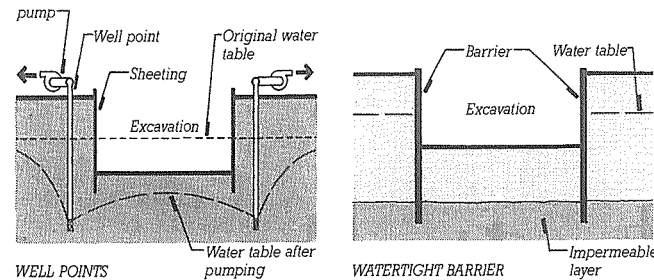


FIGURE 2.22
Two methods of keeping an excavation dry, viewed in cross section. The water sucked from well points depresses the water table in the immediate vicinity to a level below the bottom of the excavation. Watertight barrier walls work only if their bottom edges are inserted into an impermeable stratum that prevents water from working its way under the walls.

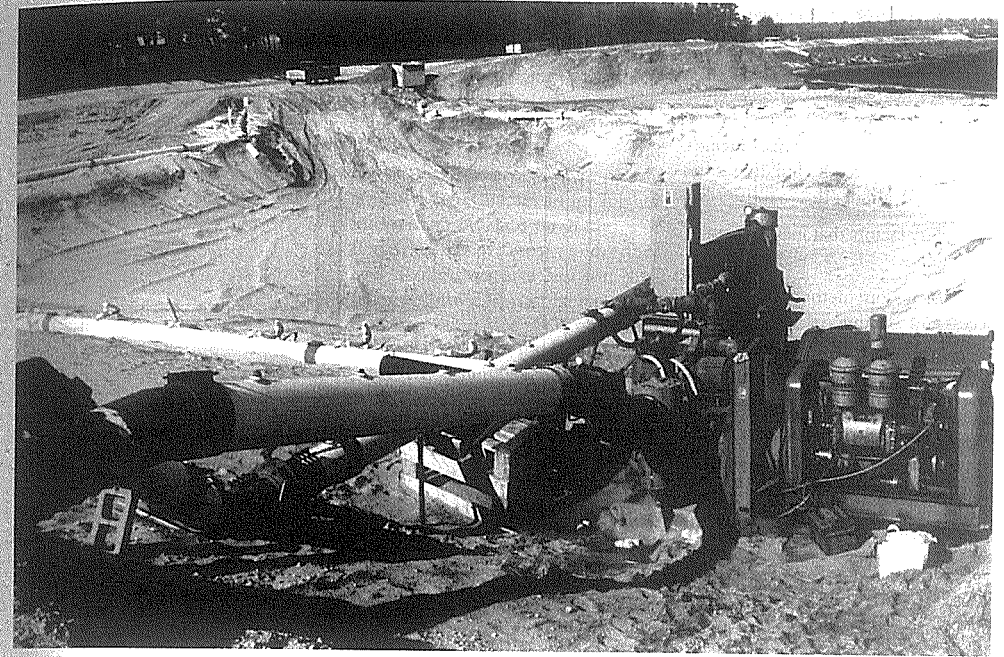


FIGURE 2.23
The pump in the foreground draws water through a header pipe that connects to well points spaced every meter or so around the perimeter of the excavation. This allows work to continue in the dry despite a high water table maintained by the lake just visible at the upper right. (Courtesy of Griffin Dewatering Corporation)

FOUNDATIONS

It is convenient to think of a building as consisting of three major parts: the *superstructure*, which is the above-ground portion of the building; the *substructure*, which is the habitable below-ground portion; and the *foundations*, which are the components of the building that transfer its loads into the soil (Figure 2.24).

There are two basic types of foundations: shallow and deep. *Shallow foundations* are those that transfer the load to the earth at the base of the column or wall of the substructure. *Deep foundations*, either piles or caissons, penetrate through upper layers

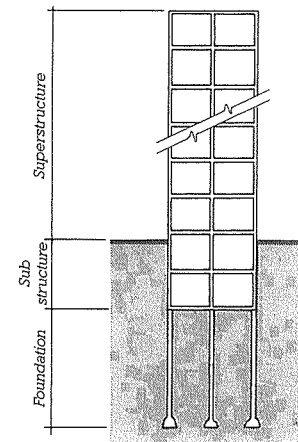


FIGURE 2.24
Superstructure, substructure, and foundation. The substructure in this example contains two levels of basements, and the foundation consists of bell caissons.

of incompetent soil in order to transfer the load to competent bearing soil or rock deeper within the earth. Shallow foundations are generally less expensive than deep ones and can be used where suitable soil is found at the level at the bottom of the substructure, whether this be several feet or several stories below the surface.

The primary factors that affect the choice of a foundation type for a building are:

- Subsurface soil and groundwater conditions
- Structural requirements, including foundation loads, building configurations, and depth

Secondary factors that may be important include:

- Construction methods, including access and working space
- Environmental factors, including noise, traffic, and disposal of earth and water
- Building codes and regulations
- Impact on adjacent property
- Time available for construction
- Construction risks

The foundation engineer is responsible for assessing these factors and, working together with other members of the design and construction team, selecting the most suitable foundation system.

Shallow Foundations

Most shallow foundations are simple concrete *footings*. A *column footing* is a square block of concrete, with or without steel reinforcing, that accepts the concentrated load placed on it from above by a building column and spreads this load across an area of soil large enough that the allowable bearing stress of the soil is not exceeded. A *wall footing* or *strip footing* is a continuous strip of concrete that serves the same function for a loadbearing wall (Figures 2.25 and 2.26).

To minimize settlement, footings are usually placed on undisturbed soil. Under some circumstances, however, footings are built on *engineered fill*, which is earth that has been deposited under the supervision of a soils engineer. The engineer, working from the results of laboratory compaction tests on samples taken from

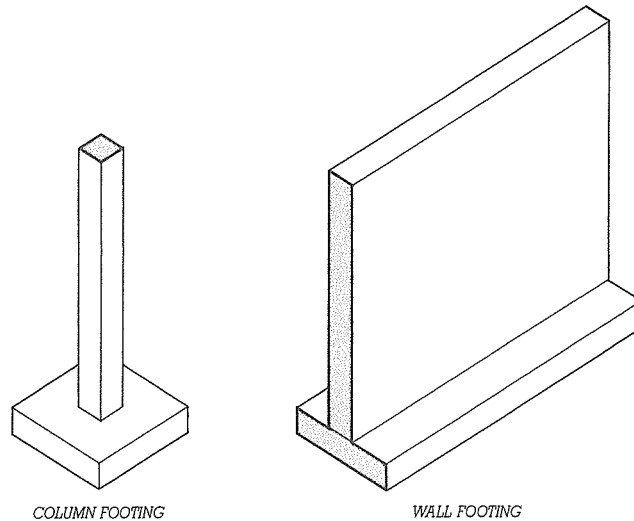


FIGURE 2.25

A column footing and a wall footing of concrete. The steel reinforcing bars have been omitted for clarity.

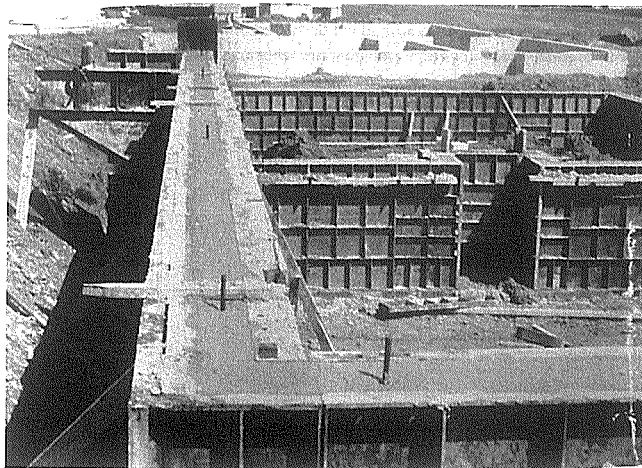


FIGURE 2.26

These concrete foundation walls for an apartment building, with their steel formwork not yet stripped, rest on wall footings. For more extensive illustrations of wall and column footings, see Figures 14.5, 14.11, and 14.13. (Reprinted with permission of the Portland Cement Association from *Design and Control of Concrete Mixtures*; Photos: Portland Cement Association, Skokie, IL)

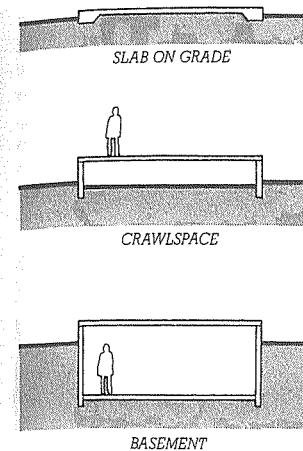


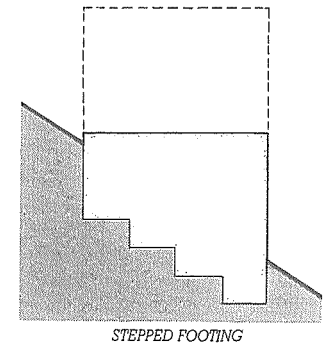
FIGURE 2.27

Three types of substructures using simple wall footings. The slab on grade is the most economical under many circumstances, especially where the water table lies near the surface of the ground. A crawlspace is often used under a floor structure of wood or steel, and gives much better access to underfloor piping and wiring than a slab on grade.

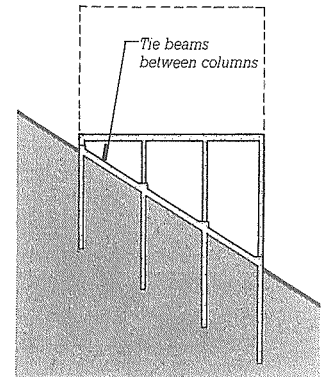
the soil used for filling, sees that the soil is deposited in thin layers at a controlled moisture content and compacted in accordance with detailed procedures that assure a known loadbearing capacity and long-term stability.

Footings appear in many forms in different foundation systems. In climates with little or no ground frost, a concrete *slab on grade* with thickened edges is the least expensive foundation and floor system that one can use and is applicable to one- and two-story buildings of any type of construction (see Chapter 14 for further information on slabs on grade). For floors raised above the ground, either over a *crawlspace* or a *basement*, support is provided by concrete or masonry foundation walls supported on concrete strip footings (Figure 2.27). When building on slopes, it is often necessary to step the footings to maintain the required depth of footing at all points around the building (Figure 2.28). If soil conditions or earthquake precautions require it, column footings on steep slopes are linked together with reinforced concrete *tie beams* to avoid possible differential slippage between footings.

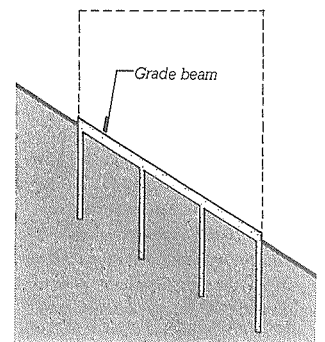
Footings cannot legally extend beyond a property line, even for a building built tightly against it. If the outer toe of the footing were simply cut off at the property line, the footing would not be symmetrically loaded by the column or wall and would tend to rotate and fail. *Combined footings* and *cantilever footings* solve this problem by tying the footings for the outside row of columns to those of the next row in such a way that any rotational tendency is neutralized (Figure 2.29).



STEPPED FOOTING



TIE BEAMS



GRADE BEAM

FIGURE 2.28

Foundations on sloping sites, viewed in a cross section through the building. The broken line indicates the outline of the superstructure. Wall footings are stepped to maintain the necessary distance between the bottom of the footing and the surface of the ground. Separate column foundations, whether caissons, as shown here, or column footings, are often connected with reinforced concrete tie beams to reduce differential movement between the columns. A grade beam differs from a tie beam by being reinforced to distribute the continuous load from a bearing wall to separate foundations.

In situations where the allowable bearing capacity of the soil is low in relation to the weight of the building, column footings may become large enough that it is more economical to

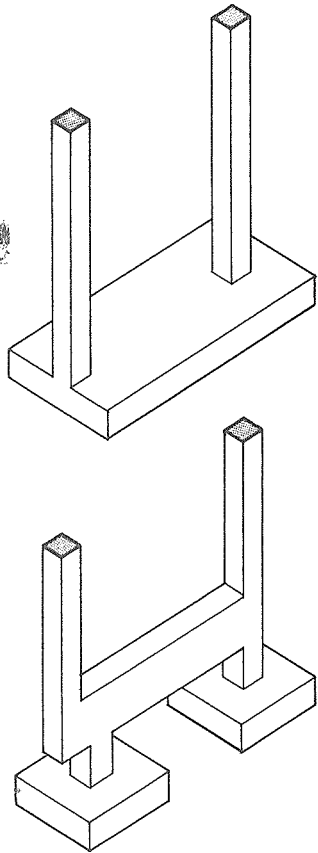


FIGURE 2.29

Either a combined footing (top) or a cantilevered footing (bottom) is used when columns must abut a property line. By combining the foundation for the column against the property line, at the left, with the foundation for the next interior column to the right, in a single structural unit, a balanced footing design can be achieved. The concrete reinforcing steel has been omitted from these drawings for the sake of clarity.

merge them into a single *mat or raft foundation* that supports the entire building. Mats for very tall buildings are often 6 feet (1.8 m) or more in thickness and are heavily reinforced (Figure 2.30).

Where the bearing capacity of the soil is low and settlement must be carefully controlled, a *floating foundation* is sometimes used. A floating

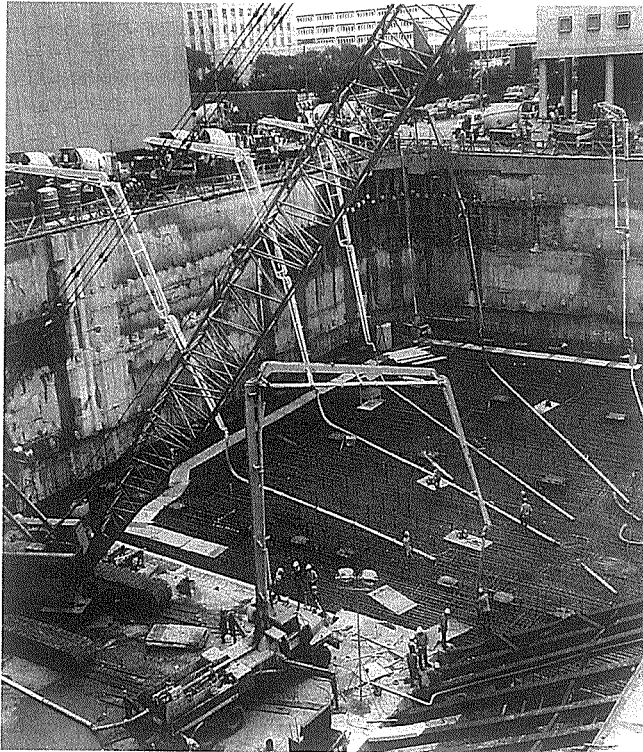


FIGURE 2.30

Pouring a large foundation mat. Six truck-mounted pumps receive concrete from a continuous procession of transit-mix concrete trucks and deliver this concrete to the heavily reinforced mat. Concrete placement continues nonstop around the clock until the mat is finished to avoid "cold joints" between hardened concrete and fresh concrete. The soil around this excavation is supported with a sitecast concrete slurry wall. Most of the slurry wall is tied back, but a set of rakers is visible at the lower right. (Courtesy of Schwing America, Inc.)

foundation is essentially the same as a mat, but is placed beneath a building at a depth such that the weight of the soil removed from the excavation is equal to the weight of the building. One story of excavated soil weighs about the same as five to eight stories of superstructure, depending on the density of the soil and the construction of the building (Figure 2.31).

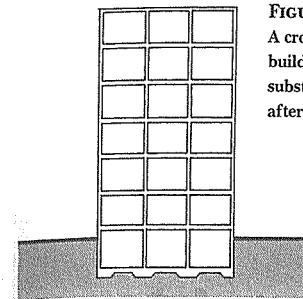


FIGURE 2.31

A cross section through a building with a floating foundation. The building weighs approximately the same as the soil excavated for the substructure, so the stress in the soil beneath the building is the same after construction as it was before.

Deep Foundations

Caissons

A *caisson* (Figure 2.32) is similar to a column footing in that it spreads the load from a column over a large

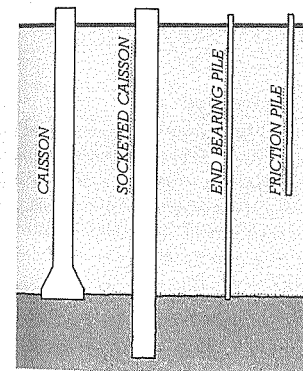


FIGURE 2.32

Deep foundations. The caissons are concrete cylinders poured into drilled holes. They reach through weaker soil (light shading) to bear on competent soil beneath. The end bearing caisson at the left is belled as shown when additional bearing capacity is required. The socketed caisson is drilled into a hard stratum and transfers its load primarily by friction between the soil or rock and the sides of the caisson. Piles are driven into the earth. End bearing piles act in the same way as caissons. The friction pile derives its load-carrying capacity from friction between the soil and the sides of the pile.

enough area of soil that the allowable stress in the soil is not exceeded. It differs from a column footing in that it extends through strata of unsatisfactory soil beneath the substructure of a building until it reaches a satisfactory bearing stratum, such as rock, dense sands and gravels, or firm clay. A caisson is constructed by drilling or hand-digging a hole, belling (flaring) the hole out at the bottom as neces-

sary to achieve the required bearing area, and filling the hole with concrete. Large *auger drills* (Figures 2.33 and 2.34) are used for drilling caissons; hand excavation is used only if the soil is too bouldery for the drill. A temporary cylindrical steel casing is usually lowered around the drill as it progresses, to support the soil around the hole. When a firm bearing stratum is reached, the bell, if required,



FIGURE 2.33

A 6-foot-diameter (1828-mm) auger on a telescoping 70-foot (21-m) bar brings up a load of soil from a caisson hole. The auger will be rotated rapidly to spin off the soil before being reinserted in the hole. (Courtesy of Caldwell Inc.)

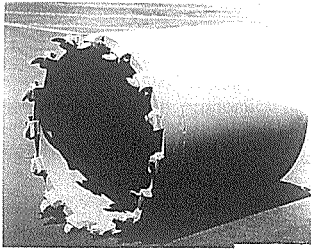


FIGURE 2.34
For cutting through hard material, the caisson drill is equipped with a carbide-toothed coring bucket. (Courtesy of Calweld Inc.)

is created at the bottom of the shaft either by hand excavation or by a special bell bucket on the drill (Figure 2.35). The bearing surface of the soil at the bottom of the hole is then inspected to be sure it is of the anticipated quality, and the hole is filled with concrete, withdrawing the casing as the concrete rises. Reinforcing is seldom used in the concrete except near the top of the caisson, where it joins the columns of the superstructure.

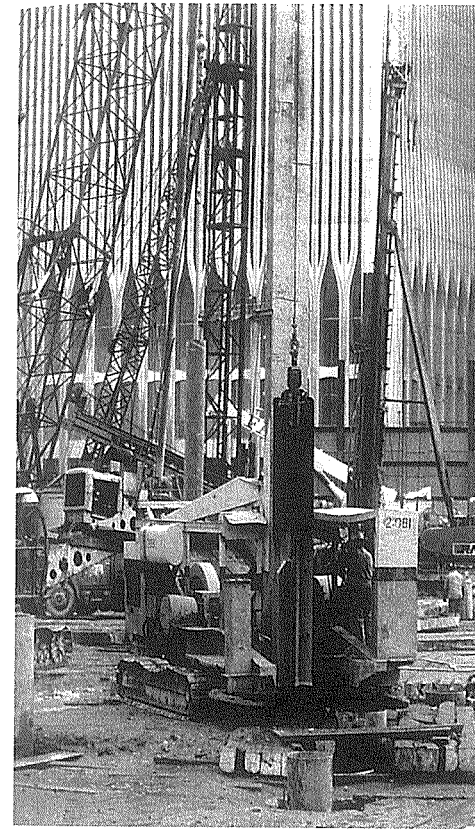
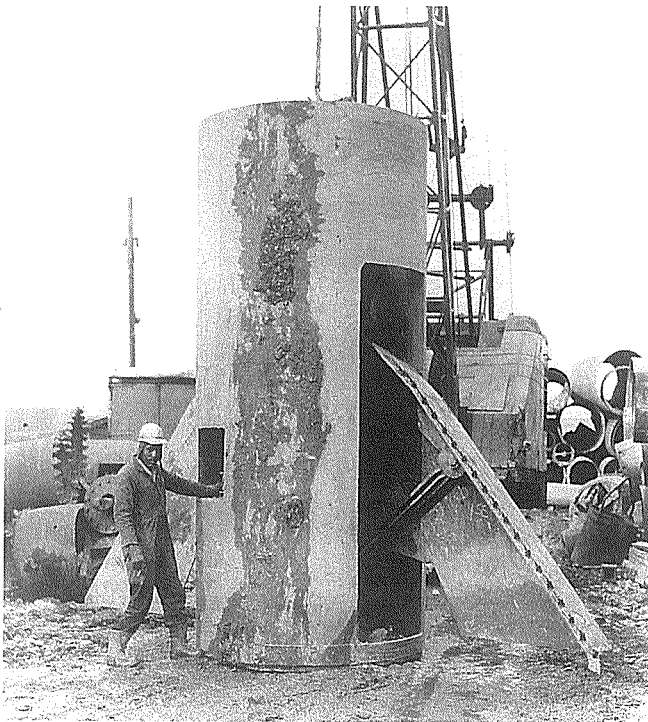
Caissons are large, heavy-duty units. Their shaft diameters range up to 8 feet (2.4 m) and more, from a minimum of 18 inches (460 mm) for a mechanical drill with a bell bucket, or 32 inches (800 mm) for hand excavation. *Belled caissons* are practical only where the bell can be excavated in a cohesive soil (such as clay) that can retain its shape until concrete is poured and where the

bearing stratum is impervious to the passage of water, to prevent flooding of the hole.

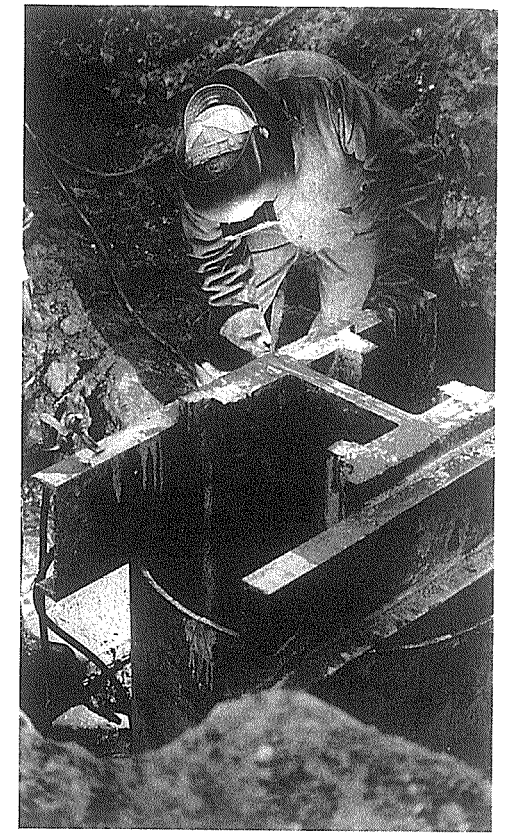
A *socketed caisson* (Figure 2.32) is drilled into rock at the bottom, rather than belled. Its bearing capacity comes not only from its end bearing, but from the frictional forces between the sides of the caisson and the rock as well. Figure 2.36 shows the installation of a rock caisson or drilled-in caisson, a special type of socketed caisson with a steel H-section core. In some soils, caissons develop their load-carrying capacity entirely by friction between the soil and the sides of the caissons.

The term “caisson” originally referred to a watertight chamber within which foundation work could be carried out underwater or below the water table. In common usage, it has also come to mean the type of deep foundation unit described in

FIGURE 2.35
The bell is formed at the bottom of the caisson shaft by a bell bucket with retractable cutters. The example shown here is for an 8-foot (2.44-m) shaft, and makes a bell 21 feet (6.40 m) in diameter. (Courtesy of Calweld Inc.)



(a)



(b)

FIGURE 2.36

Installing a rock caisson foundation. (a) The shaft of the caisson has been drilled through softer soil to the rock beneath, and cased with a steel pipe. A churn drill is being lowered into the casing to begin advancing the hole into the rock. (b) When the hole has penetrated the required distance into the rock stratum, a heavy steel H-section is lowered into the hole and suspended on steel channels across the mouth of the casing. The space between the casing and the H-section is then filled with concrete, producing a caisson with a very high load-carrying capacity because of the composite structural action of the steel and the concrete. (Courtesy of Franki Foundation Company)

the preceding paragraphs. To avoid confusion, the term *drilled pier* is sometimes used in the literature to describe the foundation unit.

Piles

A *pile* is distinguished from a caisson by being driven into the earth rather than drilled and poured. The simplest kind of pile is a *timber pile*, a tree

trunk with its branches and bark removed; it is supported small end down in a *piledriver* and beaten into the earth with repeated blows of a very heavy mechanical hammer.

If a pile is driven until its tip encounters firm resistance from rock, dense sands, or gravels, it is an *end bearing pile*. If it is driven only into softer material, without encountering

a firm bearing layer, it will still develop a considerable load-carrying capacity through the frictional resistance between the sides of the pile and the soil through which it is driven; in this case, it is known as a *friction pile* (Figure 2.32).

Piles are generally driven closely together in clusters that contain from two to twenty-five piles each. The

piles in each cluster are later joined at the top by a reinforced concrete *pile cap*, which distributes the load of the column or wall equally among the piles (Figures 2.37 and 2.38).

End bearing piles are used on sites where a firm bearing stratum exists at a depth that can be reached by piles. End bearing piles work exactly the same as caissons, but can be used where noncohesive soils or subsurface water conditions preclude the installation of caissons. Each pile is driven "to refusal," the point at which little additional penetration is made with continuing blows of the hammer, indicating that the pile has penetrated the bearing layer and is firmly embedded in it.

Friction piles are used when no firm bearing stratum exists at a reasonable depth or when a high water table would make footings or caissons prohibitively expensive. Friction piles work best in silty, clayey, and sandy soils, and they are driven to a predetermined depth or resistance rather than to refusal. Clusters of friction piles have the effect of distributing a column load to a large volume of soil

around and below the cluster, at stresses that lie safely within the capability of the soil (Figure 2.39).

The loadbearing capacities of piles are calculated in advance based on soil test results and the properties of the piles and piledriver. To verify the correctness of the calculation, test piles are often driven and loaded on the building site before foundation work begins.

Where piles are used to support loadbearing walls, reinforced concrete *grade beams* are constructed between the pile caps to transmit the wall loads to the piles (Figure 2.40). Grade beams are also used with caisson foundations for the same purpose.

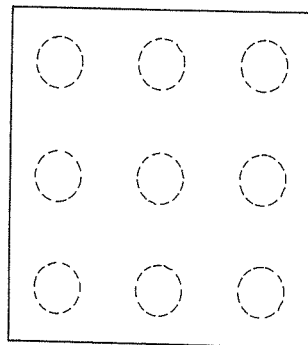
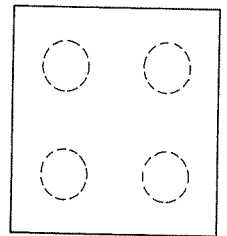
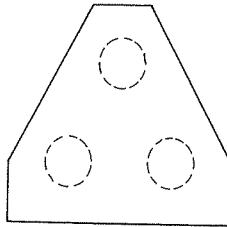
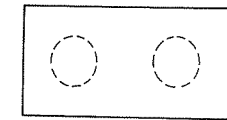


FIGURE 2.37
Clusters of two, three, four, and nine piles with their concrete caps, viewed from above. The caps are reinforced to transmit column loads equally into all the piles in the cluster, but the reinforcing steel has been omitted here for the sake of clarity.

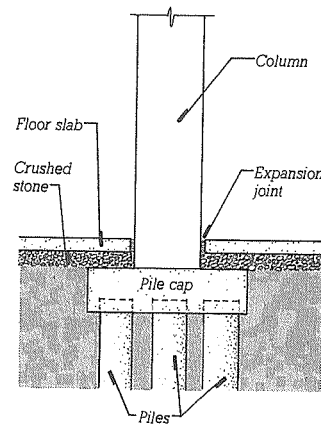


FIGURE 2.38
An elevation view of a pile cap, column, and floor slab.

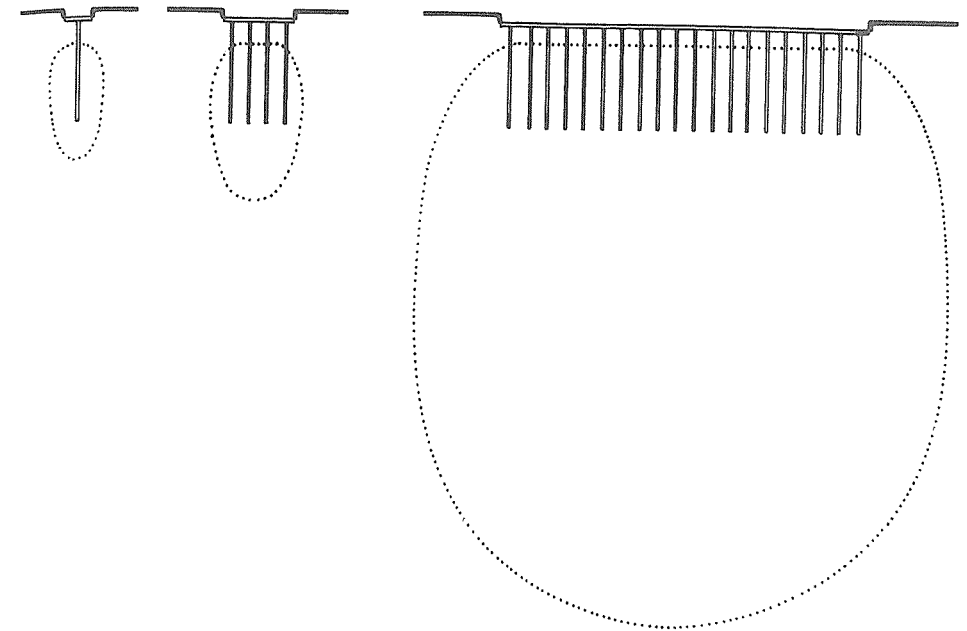


FIGURE 2.39

A single friction pile (left) transmits its load into the earth as an equal shear pressure along the bulb profile indicated by the dotted line. As the size of the pile cluster increases, the piles act together to create a single, larger bulb of higher pressure that reaches deeper into the ground. A building with many closely spaced clusters of piles (right) creates a very large, deep bulb. Care must be taken to ensure that large-pressure bulbs do not overstress the soil or cause excessive settlement of the foundation. The settlement of a large group of friction piles in clay, for example, will be considerably greater than that of a single, isolated pile.

In order to support a loadbearing wall, pile caps are joined by a grade beam. The reinforcing in the grade beam is similar to that in any ordinary continuous concrete beam, and has been omitted for clarity. A concrete loadbearing wall can generally be reinforced to act as its own grade beam.

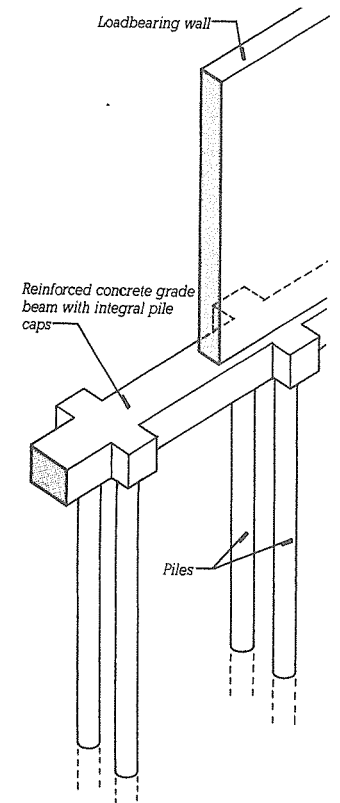


FIGURE 2.40